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Environmental Assessment of Subsurface Disposal of Municipal Wastewater Treatment Sludge

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An assessment of groundwater quality in the vicinity of eight landfill sites accepting various quantities of municipal sewage sludge was performed. An appraisal was also made of the operations and economics at each location. The study consisted of two phases. The first included a preliminary assessment of the environmental impacts of sewage sludge burial practices at the eight sites. In the second phase, additional data on leachate and groundwater quality trends over a 12-month period were obtained. Two sites were selected for more intensive groundwater monitoring to determine the areal extent and degree of groundwater quality impact. The results showed that landfilling of sewage sludge released significant contaminants in the form of leachate. Among the contaminants analyzed, iron, lead, and TOC in excess of EPA Drinking Water Standards were found most frequently. Contaminants traveled at least several hundred meters beyond the immediate disposal area, despite the existence of soil strata with low permeability. The monitoring data demonstrated the extreme difficulty in selecting monitoring well locations and sampling depths and establishing a sampling frequency necessary to obtain valid information for measuring landfill impacts on groundwater.

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SUBSURFACE DISPOSAL
OF MUNICIPAL WASTEWATER TREATMENT SLUDGE

Environmental Assessment

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FOREWORD

A major concern in any solid waste management system is the disposal of wastewater treatment sludge. The quantities of sludge to be disposed of are increasing and will continue to increase with the implementation of more stringent Federal water quality standards and best practicable treatment technology requirements. Currently 5.5 million dry tons of wastewater sludge are generated annually, and this quantity is expected to more than double by 1983.

Approximately 50 percent of the land disposal sites accepting residential and commercial wastes in this country also accept wastewater treatment plant sludge. An additional, but unknown, number of land disposal sites are specifically designed for wastewater treatment sludge only.

In order to assess the environmental effect of these sludge landfilling practices, especially on groundwater quality, the Office of Solid Waste awarded a contract to SCS Engineers. The study was conducted in two phases: Phase I was designed to detect the presence or absence of leachate-contaminated groundwater in the immediate vicinity of the disposal sites. The results of the Phase I study were published in an interim report (SW-547) September 1977.

During the Phase II study a more intensive monitoring program was initiated in order to substantiate the observed trends in Phase I, evaluate changes in groundwater quality as influenced by disposal operations, predict possible future damage to the aquifer in the area, and to assess attenuation mechanism(s) in the soil near the landfill. The results of the Phase II study are presented in this report.

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SUMMARY AND FINDINGS

An investigation of groundwater quality, disposal operations costs and aesthetics was conducted at eight landfills receiving various quantities of sewage sludge. Three sites were located in Nebraska, two in New York, and one each in New Jersey, Arkansas, and Virginia.

Four samplings of leachate, groundwater and landfill gas three times over a 4- to 6- mo period in 1975 and once in June 1976, were made in Phase I (December 1974 to January 1976). Sewage sludge samples and soil samples obtained at various depths beneath the landfill were obtained and chemically characterized. Preliminary results indicated that groundwaters in the vicinity of the landfills were contaminated with heavy metals, including iron, lead and mercury. Nitrate was present at very low to trace amounts in the leachate and groundwater. Methane and carbon dioxide were the predominant gas species found in the landfills.

Phase II monitoring (August 1976 to January 1978) was initiated to provide additional data on leachate and groundwater quality at the landfills. Leachate and groundwater samples were collected bimonthly over a 1-yr period. Analyses included total organic carbon, specific conductance, chloride, sulfate, and eight heavy metals.

A major effort in Phase II involved installation of six additional off-site wells with pneumatic ejector-type sample collectors at two sites. The wells were located to establish the three-dimensional extent of the leachate plume emanating from the landfill. Two parallel lines, each containing three off-site wells and four sampling elevations within each well, were located perpendicular to the presumed central axis of the leachate plume downgradient from the disposal area. The two vertical planes passing through the leachate-contaminated groundwater enclave, coupled with the distinguishable direction of groundwater movement, defined a hypothetical leachate control volume. Total mass emissions through the control volume, dilution, and soil attenuation were estimated based on monitoring results.

Significant findings based on the Phase II monitoring effort are summarized below:

- The intensive sampling at Sites 1 and 3 provided clear evidence of leachate presence, and the movement and variation in contaminant concentrations with sampling time, depth, and well location. The data did not verify the conventional concepts of uniform leachate emission from the entire landfill area and dispersion in a fan-shaped plume downstream of the landfill site and along the soil-groundwater interface. It appeared that the 2-mo sampling intervals were too infrequent to adequately assess groundwater quality impacts of subsurface burial of sewage sludge.

- Although distinct seasonal peaks in leachate contaminant concentrations were evident in the data, no consistent pattern emerged for the specific contaminants at a given site. Mass balance calculations for the control volumes at Sites 1 and 3 showed that TOC and chloride were attenuated, while soluble zinc and lead were eluted. Soluble iron and sulfate could be attenuated or eluted, while there was little or no change in mercury.

- No apparent correlations existed between the concentrations of selected constituents in the sludge and those found either in the leachate or groundwater. Concentrations of these constituents were significantly higher in the leachate than in the groundwater. Soil between the bottom of the landfill and groundwater greatly attenuated or decreased the potency of the leachate.

- The Phase II data confirmed the preliminary results obtained under Phase I in that iron, lead, and TOC were the contaminants in downstream groundwaters that most often exceeded EPA Drinking Water Standards. Generally, the contaminant concentrations measured in Phase II were lower than those found in Phase I. Mercury, a contaminant of concern from Phase I was not found to be of concern based on the Phase II monitoring results.

- Elevated groundwater contaminant levels during initial samplings were presumably due to disturbances from well drilling. The increases in contaminant concentrations observed to occur during the summer were believed due to larger quantities of leachate escaping from the fill sites.

- Iron in excess of EPA Drinking Water Standards appeared in several background wells and in nearly all downstream groundwater monitoring wells at the study sites. However, since its solubility is dependent on redox potential, clay content, and other ligands, iron does not appear to be suitable as an indicator of leachate metal migration. Lead was found to be a good indicator of leachate-borne heavy metals in groundwater. Downstream wells at Sites 1, 2, 3, and 4 appeared to be contaminated with lead.

- There was little discernible difference in downstream groundwater quality between sites receiving sewage sludge only and those sites accepting mixed sewage sludge and refuse, although somewhat higher lead concentrations were observed at the sludge-only sites. Using EPA Drinking Water Standards as a reference point, there was no evidence that the groundwater was contaminated by cadmium, chromium, mercury, nickel, copper, and zinc at the eight sites monitored. The high chloride and sulfate concentrations observed at two sites were the result of saltwater intrusion or the oxidation of pyrite.

Overall, the monitoring data identify the extreme difficulty in selecting monitoring well locations and sampling depths, and establishing a sampling frequency necessary to obtain valid information on landfill impacts on groundwater. Contaminant concentration isopleths illustrated in the report demonstrate multiple leachate plumes, horizontal and vertical stratification, and seasonal variations in contaminants, all within a monitoring grid measuring 160 m wide by 15 in deep. A successful effort to measure impacts on groundwater will be costly, time-consuming, and will require the participation of highly trained specialists in the initial planning and survey.

Aside from site monitoring, the aesthetics, operations, and costs were also assessed during site visits. Disposal of municipal sewage sludge in clay trenches can result in aesthetic and operational difficulties. The major aesthetic problems reported at the study sites were odors and unattractive piles of exposed sludge. From a visual and aesthetic viewpoint, certain disposal practices appeared more acceptable than others. However, the analytical results did not show that these operational practices mitigated impacts on local groundwaters. Nevertheless, none of the eight case study sites reported any discernible increase in accidents, injuries, or other health problems by site employees, site users, or the community as a result of the sludge disposal operations.

Operational problems arose primarily from the difficulty experienced by equipment operators in handling sludge piles. The high moisture content of the sludge caused wheels and tracks on equipment to spin and caused sludge to accumulate on equipment components. Soft spots occurred in the landfill where large quantities of sludge had been buried, resulting in depressions that trapped drainage or mired the equipment.

The proper handling and land disposal of septic tank pumpings was cited as a difficult problem by many site operators. The number and degree of problems encountered appear to increase with the proportion of septic tank pumpings received, primarily because the material is liquid, obnoxious, and often unstable.

The indicated cost of sludge disposal ranged from \$10.03 to \$48.95/dry metric ton at the sludge-only disposal facilities, and \$5.06 to \$69.17/dry metric ton at the mixed refuse and sludge burial facilities. These costs reflect an actual or calculated "gate fee" at each disposal site and do not necessarily indicate the actual cost incurred for sludge disposal.

A confusing picture of state and local regulatory agency requirements governing handling and disposal of wastewater treatment sludge exists in the United States. Completely dichotomous disposal philosophies and regulations are apparent from state to state. This seemingly inconsistent regulation of wastewater treatment sludge disposal has spawned a patchwork of conflicting practices. In some instances, it has fostered environmentally unacceptable overt and covert sludge disposal practices.

SECTION 1

INTRODUCTION

DESCRIPTION OF THE PROBLEM

As effluent standards become increasingly stringent, the quantity of sewage sludge produced by municipal treatment plants in meeting these standards also increases. This, in turn, creates a burgeoning sludge disposal problem. Communities throughout the country are experimenting with various methods for the disposal of sewage sludge in an attempt to evolve a method best suited to their requirements.

Past and present methods for municipal sewage sludge disposal include:

- Direct discharge to rivers, lakes, and oceans
- Incineration
- Various land burial procedures
- Agricultural utilization
- Land and/or forest application.

Environmental and economic constraints are currently forcing the reappraisal of virtually every disposal option. Ocean disposal is being phased out because of environmental and potential health considerations. Energy costs have raised incinerator operating expenses to near prohibitive levels for many communities. As a result, some communities are taking the most convenient and expeditious alternative, often with little thought to protecting the environment. Communities such as these are in need of advice and guidance as to the best alternative procedures to replace present costly or prohibited sludge disposal practices.

PROJECT DESCRIPTION

This project is part of an organized program developed by the United States Environmental Protection Agency, Office of Solid Waste, to assess the costs and environmental impacts of different methods of sludge utilization and/or disposal. The ultimate goal of this program is to develop guidelines to aid communities in selecting a cost-effective and environmentally acceptable sludge disposal method.

The broad objective of this project was to conduct an environmental assessment of subsurface placement of sewage treatment solids. Leaching of contaminants from municipal solid waste landfills is recognized as a problem at fills not designed and operated according to EPA suggested operating practices. However, it has been the belief that sanitary landfills operated under these guidelines would sufficiently mitigate or reduce the leaching potential so that there would be no adverse impacts on groundwater outside of the landfill disposal area or property boundaries. Similarly, it was theorized that there would be no adverse impacts from sludge burial in municipal landfills. To test this hypothesis, EPA funded this study to ascertain whether the leachates emanating from sites accepting municipal sewage sludge were significantly different from those accepting only municipal refuse, and whether this leachate produced an adverse impact on groundwater.

Appropriate regulatory agencies overseeing wastewater treatment and solid waste disposal in 48 states were contacted for information concerning sewage sludge disposal facilities in their respective states. Leads and recommendations from these agencies, as well as other sources, led to a preliminary investigation of over 300 such facilities in the United States. Information provided by the regulatory agencies as well as in-depth interviews and site visitations revealed a confusing picture of state and local regulatory agency requirements governing the handling and disposal of sewage sludge. Completely dichotomous disposal philosophies and regulations were apparent as the interviewer moved from one state to another. The contradictory and seemingly arbitrary regulation of sewage sludge disposal has spawned a patchwork of conflicting practices. In some instances, it has helped foster environmentally unacceptable overt and covert practices.

Follow-up telephone interviews with over 100 municipal officials revealed a general lack of knowledge on the method and location of sludge disposal in their respective communities. Oftentimes, municipal officials had little knowledge or understanding of the attendant problems. The impression that remained was that while water and wastewater was adequately regulated, sewage sludge disposal came under some ambiguous wastewater regulation. In addition, many state solid waste regulations arbitrarily exclude municipal sewage sludge or were very vague concerning handling and disposal. Only a few states evidenced a comprehensive knowledge of their sewage sludge disposal practices or had realistic and practical regulations governing the disposal of such material.

The study was conducted in two phases. The first phase (EPA Contract No. 68-01-3108, December 1974 to January 1976) involved an initial assessment of the environmental impact of wastewater treatment sludge burial practices. Tasks developed and performed to accomplish this overall objective included:

- Identification and selection of nine case study sites encompassing a representative range of sizes, soil characteristics, climatological conditions, operating techniques, sludge quantities and characteristics, and environmental impacts (actual and potential) for detailed field study

- Conduct of field studies at each location to obtain site data; historical operating and cost information; aesthetic and environmental problems encountered and approaches to problem solution; sludge quantities and physical, chemical, and biological characteristics; and disposal site operating techniques

- Location and installation of monitoring wells at each site to assess the physical and chemical characteristics of leachate and groundwaters and the composition of decomposition gases generated within the landfill.

The data obtained under the first phase determined only the presence or absence of groundwater contamination. No effort was made to provide information on the level and areal extent of groundwater contamination at these sites. Another deficiency included the lack of truly representative background groundwater samples with which to compare down-gradient groundwater and to identify contamination. Further, this initial effort encompassed less than four data points, and further analyses were required to provide statistical confidence in the results obtained.

The second phase of the study (EPA Contract No. 68-01-4166, August 1976 to January 1978) was intended to provide additional data on leachate and groundwater quality at eight of the case study sites of the initial project. Tasks under the second project included:

- Monitoring leachate and groundwater quality at eight case study sites for a specified list of contaminants at 2-mo intervals over a 12-mo period

- Measurement and evaluation of changes in groundwater quality down-gradient from two disposal sites as a function of distance and hydrogeological parameters

- Prediction of possible future damage to the groundwater aquifer in the area of all sites based on field information obtained

- Preparation of detailed case study reports for each of the eight sites

- Correlation of observed differences in concentrations and areal extent of pollutant contamination among the eight sites with the following parameters:

  - Types and quantities of wastes buried
  - Climate
  - Geology
  - Hydrology

- Assessment, where possible, of the mechanism(s) of concentration or attenuation as the leachate passes from the waste/soil interface to groundwaters.

A major objective of the study was to determine the areal extent and degree of contamination from landfills accepting municipal sewage sludge/refuse admixtures. Two sites were selected from eight previously monitored sites for a more extensive monitoring program. These two sites were carefully chosen to allow a comparison of two different soil conditions, and sewage sludge only versus combined sludge/municipal refuse disposal. Six pneumatic sampling wells were installed downgradient from each disposal site to intercept and sample the leachate plume as it moved from the landfill in the direction of the regional groundwater movement. These six wells were arranged in two parallel lines perpendicular to the direction of groundwater flow. In addition, each well was designed to allow sampling of the groundwater at four depths. This arrangement created a test box with 12 sample points on each face intersecting the flow. Any difference between concentrations of constituents at each face could be attributed to dilution, attenuation, or elution, depending on the type and magnitude of the change and any inputs to the box other than the leachate plume.

REPORT ORGANIZATION

This report includes the results of both phases of the project and is organized into two volumes. Volume 1 discusses project execution, interpretive findings, and recommendations based on the field and analytical results and has been organized into the following topic areas:

- A brief description of the individual case study sites highlighting climatological, geological, and topographical features; operating practices; descriptions of refuse and/or sewage sludge quantities and characteristics and contributing sources of sludge; and any other notable events that may affect the environment

- A description of the design and installation of the field monitoring devices
- Sampling and analytical program and quality control procedures
- Analytical results and data evaluation for each site and a discussion of trends and relationships observed.

Volume 2, Case Study Site Reports, contains a detailed description of each site, with brief site-specific interpretations and evaluations of the findings.

SECTION 2

SITE SELECTION PROCEDURES

SITE SELECTION CRITERIA

Criteria used in the initial screening and selection of candidate case study sites were prepared at the project's onset. Several mandatory criteria were stipulated in the contract while other desirable criteria were identified to aid in ensuring a successful project. Following are the mandatory criteria:

- Subsurface placement of sewage treatment solids at the site must have been or was practiced for at least 1 yr, and the site must not have been closed for more than 3 yr prior to the start of the survey.
- One-third of the sites selected were to dispose of sewage sludge only while the remainder were to dispose of sewage sludge together with municipal refuse.
- For those sites disposing of both municipal refuse and sewage sludge, the sewage sludge must have comprised at least 10 percent of the combined total quantity by weight.
- The disposal method used was to be either by sanitary landfill or pit and trench methods (liquid sewage sludge injection methods were specifically excluded).
- The sludges could have been municipal wastewater treatment sludges and/or septic tank pumpings or any combination of these wastes with municipal refuse (industrial sludges were exluded).
- As a group, the sites selected were to cover a representative range of sizes, soil characteristics, climatological conditions, operating techniques, sludge quantities and characteristics, and actual or potential environmental impacts.
- The entity responsible for the site had to agree to cooperate during the monitoring program (such cooperation was essential if the contractor's personnel were to obtain samples from the site and additional

information on site operations, handling procedures, and other pertinent information necessary to the goals of the project).

The desirable criteria included the following:

- The existence of good operational records for the disposal site (especially helpful in this regard would be historical records of quantities and types of waste received, chemical and physical characteristics of the waste, the sources of sludge material, and the areas in the landfill where sludge was placed)
- Data on area groundwater quality prior to start-up of the operation as well as the existence of climatological data from a nearby weather station
- A site previously researched by university groups and state or local regulatory agencies that would yield useful background data for comparative purposes
- Sites where existing groundwater/leachate monitoring and/or gas sampling systems are installed (such sites could provide a long-term historical data record to supplement and complement the information obtained during this study's short-term monitoring program)
- Sites maintaining current topographic maps of the area since the initiation of filling operations, as well as geological and/or engineering reports pertaining to the site and its developments, would be beneficial
- The selection of exemplary sites was not considered essential as the selection of average or probably below average operations would perhaps provide a better indication of the possible severity of environmental contamination resulting from sewage sludge disposal.

APPROACH TO SITE SELECTION

Several approaches, capsulated below, were employed to locate candidate sites for possible inclusion in the study:

- A search of the literature for references to locations where various aspects of sludge disposal to landfill had been or were being investigated
- A review of U.S. Public Health Service Bulletin No. 1866, "1968 National Survey of Community Solid Waste Practices"

- Contacting State Solid Waste Management and Wastewater Quality Control Agencies to enlist assistance in locating candidate sites meeting the mandatory criteria stipulated above (similar inquiries were made to all EPA Regional Offices)

- Contacting sewage treatment plants and/or public works departments in the largest 150 cities in the United States by telephone to ascertain how sewage sludge was being disposed of in the respective communities.

The PHS Bulletin reports on field investigations of more than 6,000 land disposal sites in the United States. Basic data pertaining to each site are tabulated, including the volume of sewage treatment sludge disposed of with other municipal solid wastes. A review of Volumes 1 and 2 (volumes for the Central and Western parts of the United States have not been published) was made to provide a quick initial screening of potential candidate sites along the East Coast. Unfortunately, the document proved of less value than originally anticipated due to closure of many sites and changes in disposal practices over the interim 7-yr period. Most of the data was found to be obsolete and no longer useful for the purposes of the project.

State agency and Regional EPA contacts, coupled with the information obtained from the literature, provided an initial list of some 200 candidate sites that were then contacted by telephone. The sewage treatment plant was initially contacted to obtain pertinent information on treatment plant operations and types and quantities of sewage sludge. The party responsible for landfill disposal operations was contacted with regard to quantities of sewage sludge received, total quantity of refuse handled, how long the site had been receiving this material, whether or not industrial wastes were being received, and other pertinent information. Telephone contact with more than one individual was useful in that it provided a cross-check on the validity of the information obtained.

Unfortunately, upon further investigation, only a very few sites actually met all of the mandatory selection criteria. The major causes for site rejection in descending order of occurrence and importance were as follows:

- The relative weight or percentage of sewage sludge solids commonly landfilled was less than 1 or 2 percent of the total instead of the desired 10 percent or more.

- The disposal of sewage sludge solids at the site:

  - Had been conducted for less than 1 yr, thus presenting little probability of any measurable environmental impacts

  - Had been discontinued after a short time because of unspecified operating difficulties

  - Had been sporadic in occurrence, and thus was deposited in unidentifiable locations in the landfill

  - Had stopped more than 3 yr ago

  - Had been used with soil cover and not buried.

- Inadequate records had been kept on the quantities of material deposited and other data considered useful in assessing and correlating the monitoring results.

- Many of the sites that accepted large quantities of sewage sludge also accepted industrial wastes, including industrial sludges.

RESULTS OF SITE INVESTIGATIONS

Following a careful review of site data and the selection criteria, the list of candidate sites totaled some 40 sites. Subsequently, a total of 31 sites were actually field-visited in an attempt to identify sites meeting the mandatory and desired criteria to the maximum possible degree.

The field visit encompassed a full man-day effort to assemble pertinent information with regard to the site. This covered two or three distinct areas as summarized below:

Sewage Treatment Plant

At the treatment plant, the following information was solicited:

- Year plant started

- Treatment or stabilization method for sewage and sludge

- Sewage sludge disposal practices since the plant became operational

- Availability of sludge quantity records for the years of operation

- Chemical, physical, and biological characterization data on sludge

- Methods and frequency of transporting sludge.

Disposal Site

The disposal site was visited and the site owner or operator queried as to the following information:

- Year site first operated
- Year that sludge was first received
- Site plan and delineation of where sludge has been buried
- Operational methods of handling and burial of refuse and/or sludge
- Operational problems related to sludge handling
- Current and past environmental monitoring programs, if any
- Availability of hydrogeologic information
- Regulatory agency requirements with regard to landfill operations and/or sludge burial.

Other Information Sources

If a local or state regulatory agency had been active in establishing operating requirements or monitoring at the landfill site, the following information was solicited:

- Monitoring results with regard to environmental and health implications of the sludge-burial operation
- Water quality data as well as geologic profiles for the area of the landfill
- Surface soil data from the Soil Conservation Service of the U.S. Department of Agriculture.

Information obtained from the site visit was evaluated and compared with telephone-derived data, and recommendations for site inclusion or exclusion derived. Nine case study sites were ultimately selected, monitoring work completed, and detailed descriptive and comparative information compiled.*

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*Monitoring wells at one location were inadvertently destroyed. Thus, only eight locations are discussed in the report.

SECTION 3

DESCRIPTION OF CASE STUDY SITES

Selected comparative information is presented in this section to characterize and identify the range of conditions found at the case study site locations.

LOCATION

The eight case study sites were located in the Midwest and Eastern sectors of the country. Three sites were located in Nebraska, two in New York, and one each in New Jersey, Arkansas, and Virginia.

CLIMATE

Selected climatic characteristics of the eight sites are presented in Table 1 and were representative of the Midwestern and Eastern seaboard areas.

Normal annual precipitation of the four Midwestern locations ranged from 59.4 to 108 cm (23.4 to 42.4 in). Annual precipitation at the four Eastern locations ranged from 82.6 to 115 cm (32.5 to 45.4 in). Site 1 in the Midwest received the least annual precipitation, 59.4 cm (23.4 in), of the eight sites, while Site 6 on the Eastern seaboard with 115 cm (45.4 in) had the highest average annual precipitation. All locations were subject to snow and ice in the winter months.

Maximum average daily temperatures of the four Midwestern sites ranged from 16.7 to 21.1°C (62 to 70°F). Minimum average daily temperatures ranged from 3.4 to 8.3°C (38 to 47°F). Corresponding average daily maximum and minimum temperatures for the four sites located in the East ranged from 12.3 to 19.3°C (54 to 67°F) and 1.4 to 8.8°C (35 to 48°F), respectively.

Site 4 in the southern Midwest had consistently higher average daily maximum and minimum temperatures, while Site 8 in the Northeast experienced the lowest average daily maximum and minimum temperatures.

TABLE 1. COMPARATIVE WEATHER DATA*

	Precipitation (cm)†					
	Water Equivalent			Snow, Ice Pellets		Mean Number of Days Precipitation
Site	Normal (Annual)	Maximum (Monthly)	Maximum (24 hr)	Maximum (Monthly)	Maximum (24 hr)	(0.025 cm or more)
1	59.4	35.6	13.7	66.0	30.5	88
2	67.8	19.0	6.8	50.3	26.4	96
3	76.7	34.8	16.5	69.1	46.5	99
4	107.7	36.1	24.4	34.3		
5	98.8	36.3	18.2	54.1	36.6	111
6	115.3	33.3	16.5	89.4	36.6	112
7	84.8	22.9	11.4	146.0	55.6	135
8	82.6	29.2	9.1	144.0	41.9	153

TABLE 1 (Continued)

Site	Temperature, $^{o}C^{\#}$			Mean Number of Days			
	Normal			Maximum		Minimum	
	Daily Maximum	Daily Minimum	Monthly	$32^{o}C$ and Above	$0^{o}C$ and Below	$0^{o}C$ and Below	$-17.8^{o}C$ and Below
1	16.7	3.4	10.0	40	45	149	16
2	16.8	4.3	10.6	37	40	141	18
3	17.1	4.6	10.8	34	40	137	12
4	21.1	8.3	14.7	48	7	91	1
5	19.3	8.8	14.0	37	9	75	0
6	17.6	6.6	12.0	16	15	111	1
7	14.5	2.8	8.7	8	47	155	17
8	12.3	1.4	6.9	5	75	163	28

*Source: U.S. Department of Commerce.

†Multiply tabulated values by 0.397 to obtain inches.

#F = ^{o}C x 1.8 -32. For example, $-17.8^{o}C = 0^{o}F$.

OWNERSHIP AND OPERATION

A comparison of site ownership and operating information is presented in Table 2. Two locations, Sites 5 and 7, had formerly operated as open dumps with intermittent burning. Each has since been converted to sanitary landfill procedures. Only one site was owned by a private firm. Of the remaining seven locations, all were municipally owned and operated except Site 1 where a private contractor operated the municipally owned site.

Three of the eight sites accepted only sludge while the remaining five sites accepted both sludge and mixed refuse. The respective costs for sludge burial were calculated on the basis of gate fees, lump sum payments to contractors, or annual operating budgets. Cost per t* of dry sludge solids ranged from $5.06 at Site 2 to $69.17 at Site 6.

Personnel employed at the sites generally ranged from one to three, with the largest site operated by a staff of 35.

Wastes were delivered by open-top truck to all of the sites. Haul distances ranged up to 19.3 km one way.

SLUDGE DESCRIPTION

Comparative information on sludge type, sludge solids content, and estimated quantities of sludge and other wastes (if any) delivered to the case study sites is given in Table 3.

Sludge received at six of the sites was described as dewatered raw primary and waste-activated sludge. Site 6 received anaerobically digested sludge and large quantities of septic tank pumpings. Site 5 received a mixture of raw and digested primary and waste-activated sludge along with minor quantities of incinerated sludge residue.

Solids content of the sludge as received for disposal ranged from about 3 percent at Site 6 to 40 percent at Sites 3 and 7. Site 3 receives relatively dry paunch manure while Site 7 receives Zimpro-processed sludge.

The relative proportion of sludge to all wastes received ranged from a low of 5.2 percent (volume basis) at Site 6 to 23.5 percent (weight basis) at Site 7.

GROUNDWATER DEPTH

The depths to groundwater at the monitoring well locations for each case study site are shown on Table 4. Calculated

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*t = metric ton.

TABLE 2. SELECTED DESCRIPTIVE INFORMATION ON CASE STUDY SITES

Criteria	Case Study Site 1	2	3	4
Ownership	Municipal	Municipal	Municipal	Municipal
Operation	Private	Municipal	Municipal	Municipal
Year opened	1969	1956	1939	1968
First received sludge	1969	1967	1939	1968
Remaining life (estimated years)	4	2	Closed	2
Open to public	Yes	Yes	No	No
Scales	No	No	No	No
Gate fee	Yes	No	No	No
Operating personnel	3	3	1	2
Equipment (number and type)	John Deere 646 compactor Caterpillar 977 with 1.9 m^3 bucket	3 Caterpillar D-8 track dozers each with 0.76 m^3 dragline	I-H 175 loader with 1.9 m^3 bucket J. Deere with .57 m^3 dragline	Backhoe
One-way haul distance in km (treatment plant to site)	8	6.4	Two plants, one adjacent to disposal site, one 16 km from site	Plant adjacent to disposal site

TABLE 2 (Continued)

Criteria	Case Study Site 5	 6	 7	 8
Ownership	Municipal	Municipal	Municipal	Private
Operation	Municipal	Municipal	Municipal	Municipal
Year opened	Dump 1925 Landfill 1972	1955	Dump 1947 Landfill 1960	1973
First received sludge	1973	1962	1972	1973
Remaining life (estimated years)	3	16	12-17	4
Open to public	No	No	Yes	No
Scales	Yes	No	No	No
Gate fee	Yes	No	No	No
Operating personnel	47	3	2	1-6
Equipment (number and type)	3 compactors 5 dozers 3 scrapers 2 track loader 1 grader 5 miscellaneous	1 dozer 1 loader	1 front-end bucket loader (2.3 m^3) 1 caterpillar D-5 dozer 1 compactor	1 Michigan 754 loader with 1.9 m^3 bucket 1-2 Caterpillar D-6 dozers

TABLE 2 (Continued)

Criteria	Case Study Site 1	 2	 3	 4
Haul vehicle	Open dump truck ($4.6\ m^3$)	Open dump truck ($6\ m^3$)	Open dump truck ($4.6\ m^3$)	2 Open dump trucks ($7.6 - 9\ m^3$)
Waste types received (annual quantities), wet basis	Sludge cake ($13,230\ m^3$) Paunch manure ($330\ m^3$) Industrial and commercial wastes ($16,800\ m^3$) Residential ($59,700\ m^3$)	Construction and demolition, municipal refuse, pretreated industrial plating sludges, paunch manure (200,000 t) Wastewater treatment sludge (25,880 t)	Dewatered grit and screenings, wastewater treatment sludge and paunch manure (varies)	Sludge (7,200 t */ yr - 5 yr average)
Disposal method	Sludge spread with refuse, compacted and covered with soil	Trench, covered with refuse and soil	Pit, covered with soil	Trench, covered with soil
Disposal costs ($/dry t)	$7.67	$5.06	$10.03	$48.95

TABLE 2 (Continued)

Criteria	Case Study Site 5	 6	 7	 8
One-way haul distance in km (treatment plant to site)	13-32 (5 plants)	8-16 (2 plants)	9.6	19.3
Haul vehicle	Trailers (13.6 t) Dump trucks (6-9 t) Tandem axle trucks, roll-off containers (4.5 t)	Vacuum tank truck ($23\ m^3$)	Open dump trucks ($3.8 - 4.6\ m^3$)	Trailers ($20 - 21.5\ m^3$)
Waste types received (annual quantities), wet basis	Sludge (53,190 t) Refuse (471,700 t)	Household and commercial refuse ($37{,}700\ m^3$) Septic tank pumpings ($7{,}200\ m^3$) Municipal wastewater treatment sludge ($3{,}590\ m^3$)	Municipal refuse (17,360 t) Sludge (5,322 t)	Sludge, screenings and grit ($53{,}500\ m^3$)
Disposal method	Sludge spread with refuse, compacted and covered with soil	Sludge dumped on refuse, covered with soil	Sludge dried in piles, then spread with refuse, covered with soil	Sludge is lagooned, allowed to dry, and covered with soil
Disposal cost, ($/dry t)	$23.29	$69.17 (operating cost)	$11.44	$21.82

* t = metric ton.

TABLE 3. VARIATION IN WASTE COMPOSITION

Criteria	Case Study Site 1	 2	 3	 4
Sludge type	Raw primary and waste activated sludge, gravity thickened, and vacuum filtered (polymers)	Raw primary and waste activated sludge, gravity and/or air flotation thickening, and vacuum filtered (polymers)	Raw primary and waste activated sludge, vacuum filtered, and paunch manure	Raw primary and waste activated sludge, gravity thickened, vacuum & filtered (lime and ferric chloride)
Solids content of sludge (as delivered to site)	25 - 30%	20 - 25%	25 - 40%	18 - 25%
Annual sludge quantity (wet basis)	13,556 m^3 (5-yr average)	25,880 t^*	Varies radically due to incinerator breakdown	7,210 t (5-yr average)
Total annual quantity of waste delivered to site	90,090 m^3	225,654 t	Varies	7,210 t
Proportion of sludge to total waste (wet basis)†	15.1%	11.5%	NA	100%

TABLE 3 (Continued)

Criteria	Case Study Site 5	 6	 7	 8
Sludge type	Anaerobically digested and dewatered sludge, lime and ferric chloride treated raw sludge incinerator residues	Anaerobically digested sludge, septic tank pumpings	Raw primary and waste activated, Zimpro processed, vacuum filtered	Raw primary and waste activated sludge gravity thickened, centrifuged
Solids content of sludge (as delivered to site)	20 - 95% (average 22%)	3 - 5%	37%	12½%
Annual sludge quantity (wet basis)	53,190 t	3,586 m^3	5,322 t	53,522 m^3
Total annual quantity of waste delivered to site	497,720 t	68,904 m^3	22,681 t	53,522 m^3
Proportion of sludge to total waste (wet basis)†	10.6	5.2	23.5	100%

*t = metric ton.
†Proportion based on either wet weight or wet volume basis depending on quantity data.

TABLE 4. DEPTHS TO GROUNDWATER

Site	Depth from Surface (m) Refuse Well	 Off-Site Wells	Depth from Bottom of Landfill (m)
1	10.7	5.5	3.4
2	8.2	2.3 to 4.1	-0.9
3	9.0	6.7	2.6
4	Drilling stopped upon reaching bedrock. Nearby portable water obtained from the 45.7 to 61 m depth.		
5	9.75	2.9	2.4
6	7.6	1.8	1.8
7	11.9	4.3 to 6.1	4.6
8	3.0	1.1	0.6

depths to groundwater below the bottom of the landfill are also presented.

Only Site 2 had sludge deposited within the first 0.9 m (3 ft) of the seasonally fluctuating groundwater table. The other locations ranged from 0.6 m (2 ft) above the groundwater table at Site 8 to an estimated 4.6 m (15 ft) above the groundwater at Site 7.

SURFACE AND SUBSURFACE SOILS

A general categorization of soil types found at each of the sites to bedrock or parent material is described in Table 5. Soil conditions varied considerably at each site. Only the prevailing soil characteristics are shown.

Soil textures and permeability coefficients for the landfill cover soils found in the vicinity of the in-refuse monitoring wells are given in Table 6. Two or more samples were tested at each site. Permeabilities are expressed as a vertical and horizontal factor for each soil.

TABLE 5. SOILS AND GEOLOGY

Site 1

Silty clay and silt
Fine sand
Clay
Sand-gravel

Site 2

Silty clay
Silt
Sand and sands-gravels
Sandstone

Site 3

Silty clay
Silty fine sand
Sand
Limestone

Site 4

Sandy loams
Limestone
Sand and calcareous sandstone
Limestone

Site 5

Unconsolidated sediments
(fine sands, silts,
clays, and gravel)
Metamorphic and igneous rocks
Granites

Site 6

Alluvial beach sand and gravel
Gray clay and fine gravel
Sand

Site 7

Glacial and alluvial deposits
Shale

Site 8

Sand and gravel
Glacial deposits

TABLE 6. SOIL TEXTURE AND PERMEABILITY COEFFICIENTS FOR COVER SOILS AT STUDY SITES

		Permeability Coefficient (cm/sec)	
Site	Soil Texture*	Horizontal	Vertical
1	Clayey sand	1.8×10^{-6} 1.4×10^{-7}	1.6×10^{-6} 1.1×10^{-7}
2	Silty clay	1.2×10^{-9}	1.2×10^{-9}
3	Silty clay	4.8×10^{-9}	9.4×10^{-9}
4	Silty clay	3.4×10^{-8}	7.4×10^{-9}
5	Clayey sand	4.12×10^{-6}	3.19×10^{-6}
6	Sand	4.5×10^{-4} 7.5×10^{-4}	1.7×10^{-3} 5.4×10^{-3}
7	Sand	1.2×10^{-3} 6.1×10^{-6}	2.0×10^{-4} 2.7×10^{-6}
8	Sand	4.5×10^{-5}	3.3×10^{-5}

* Visual classification (Unified soil classification).

SECTION 4

FIELD INSTRUMENTATION AND MONITORING PROGRAM

INTRODUCTION

Site geological surveys, well placement, sampling, and chemical analysis form an integral part of the groundwater monitoring at each of the disposal sites in this study.

During Phase I, the monitoring objective was limited to determining the presence or absence of groundwater contamination. A more intensive monitoring program was initiated in Phase II, including a geological survey; installation of exploratory, background, and additional off-site wells downstream from the disposal sites; and more frequent sampling. The objectives were to:

- Substantiate the observed trends in Phase I
- Evaluate changes in groundwater quality as influenced by disposal operation
- Predict possible future damage to the aquifer in the area
- Assess attenuation mechanism(s) in soil beneath the landfill.

GEOLOGICAL SURVEY

Prior to well placement in Phase I, available information on site geology, hydrogeology, soils, topography, and other historical data was assembled and reviewed. In Phase II, a local geology consultant assisted the project team in conducting a geological survey and in identifying locations for three exploratory wells to groundwater. A soil boring log was then prepared for each of the exploratory wells drilled. Information generated included the following:

- Visual field classification of soils
- Estimations of soil permeabilities and porosity
- Groundwater depth and direction of flow

- Direction and approximate width, length, and depth of the downstream leachate plume.

Based on this information, a background monitoring well upstream and, depending on the site, one to six off-site wells were located downstream from the landfill.

WELL INSTALLATIONS

Two sets of monitoring wells were installed at each of the study sites:

- The initial installations in 1975 (Phase I), which included an in-refuse well and one or two off-site wells

- A complementary set of wells in 1976 (Phase II), which included a background well and from one to six off-site wells (Sites 1 and 3 only).

The types of monitoring wells installed, depth, well size, and sample intake elevation are given in Table 7. Typical monitoring well placement procedures are summarized in Appendix A. Well locations at each site are shown in Figures 1 through 8. Periodic groundwater elevation readings are given in Appendix B.

Background Well

Due to the preliminary nature of Phase I, no background well was installed at any of the study sites. Instead, well water from nearby residential or commercial installations was used as the background water reference. In Phase II, after the direction of groundwater flow was established from the piezometric groundwater levels measured in the exploratory wells and geologic data, a background well was installed upstream of the disposal site in a location unaffected by landfill leachate. This background well presumably intercepted the same aquifer as the downgradient off-site wells.

The background well consisted of either a 3.8-cm or 10.2-cm PVC pipe placed to a depth of at least 2.4 m below the groundwater surface. A schematic of the background well is illustrated in Figure 9.

At Sites 1 and 3, four discrete pneumatic ejection devices for sample collection were installed at different depths in the background groundwater monitoring well. Details of this pneumatic ejector-type sample collector will be presented later under "Off-Site Well."

TABLE 7 . WELL CONSTRUCTION DETAILS FOR ALL SITES

Well Type	Drill Depth (m)	Sample Intake Elevation (m)	Well Size (cm)*
Site 1			
Initial Wells			
In-Refuse (IR)	11.3	563.0	7.6
Downstream Shallow (OS-X)	5.8	558.4 A†	7.6
Observation Wells (EX-1)	19.8	558.4	3.8
(EX-2)	16.8	556.3	"
(EX-3)	13.7	557.2	"
Gas Ejection Type Wells			
Background, Level 1 (BG-1)	18.3	557.2 C†	6.4#
Level 2 (BG-2)		554.1 A	"
Level 3 (BG-3)		551.1 A	"
Level 4 (BG-4)		548.0 A	"
Offsite No. 1, Level 1 (OS-11)	22.3	554.1 A	6.4#
Level 2 (OS-12)		550.8 A	"
Level 3 (OS-13)		547.7 A	"
Level 4 (OS-14)		545.9 A	"
Offsite No. 2, Level 1 (OS-21)	22.6	555.7 C	6.4#
Level 2 (OS-22)		552.6 A	"
Level 3 (OS-23)		549.6 A	"
Level 4 (OS-24)		547.1 A	"
Offsite No. 3, Level 1 (OS-31)	24.4	559.9 C	6.4#
Level 2 (OS-32)		556.9 C	"
Level 3 (OS-33)		553.8 A	"
Level 4 (OS-34)		550.8 A	"
Offsite No. 4, Level 1 (OS-41)	20.1	554.1 S†	6.4#
Level 2 (OS-42)		551.4 S	"
Level 3 (OS-43)		548.3 C	"
Level 4 (OS-44)		545.0 A	"
Offsite No. 5, Level 1 (OS-51)	21.3	557.8 C	6.4#
Level 2 (OS-52)		554.7 A	"
Level 3 (OS-53)		552.0 A	"
Level 4 (OS-54)		549.2 A	"
Offsite No. 6, Level 1 (OS-61)	24.4	559.3 C	6.4#
Level 2 (OS-62)		557.2 C	"
Level 3 (OS-63)		553.2 A	"
Level 4 (OS-64)		550.4 A	"
Site 2			
In-Refuse (IR)	11.0	340.5	10.2
Downstream Shallow (OS-1)	3.7	341.7	10.2
Downstream Deep (OS-2)	15.2	334.4	10.2

TABLE 7 (continued)

Well Type	Drill Depth (m)	Sample Intake Elevation (m)	Well Size (cm)[*]
Observation Wells (EX-1)	≃16.8	≃336.2	3.8
(EX-2)	≃15.2	≃335.6	"
Background Wells (BG)	6.7	340.8	10.2
Site 3			
Initial Wells			
In-Refuse (IR)	10.7	304.3	7.6
Downstream Shallow (OS-X)	7.3	300.5	7.6
Observation Wells (EX-1)	13.7	≃296.6	3.8
(EX-2)	15.2	≃295.4	"
(EX-3)	9.1	≃299.0	"
(EX-4)	9.1		"
(EX-5)	15.2		"
Gas Ejection Type Wells			
Background, Level 1 (BG-1)	18.3	302.0 C[†]	6.4[#]
Level 2 (BG-2)		299.0 C	"
Level 3 (BG-3)		296.0 S[†]	"
Level 4 (BG-4)		292.9 S	"
Offsite No. 1, Level 1 (OS-11)	19.8	299.6 C	6.4[#]
Level 2 (OS-12)		295.7 S	"
Level 3 (OS-13)		292.6 S	"
Level 4 (OS-14)		290.5 S	"
Offsite No. 2, Level 1 (OS-21)	19.8	303.0 C	6.4[#]
Level 2 (OS-22)		300.0 C	"
Level 3 (OS-23)		296.6 S	"
Level 4 (OS-24)		294.4 S	"
Offsite No. 3, Level 1 (OS-31)	19.2	299.6 C	6.4[#]
Level 2 (OS-32)		296.6 S	"
Level 3 (OS-33)		293.2 S	"
Level 4 (OS-34)		290.8 S	"
Offsite No. 4, Level 1 (OS-41)	19.2	298.4 C	6.4[#]
Level 2 (OS-42)		295.4 S	"
Level 3 (OS-43)		292.3 S	"
Level 4 (OS-44)		289.9 S	"
Offsite No. 5, Level 1 (OS-51)	19.2	298.4 C	6.4[#]
Level 2 (OS-52)		296.0 S	"
Level 3 (OS-53)		292.3 S	"
Level 4 (OS-54)		289.0 S	"
Offsite No. 6, Level 1 (OS-61)	17.7	301.4 C	6.4[#]
Level 2 (OS-62)		297.2 S	"
Level 3 (OS-63)		293.5 S	"
Level 4 (OS-64)		291.1 S	"

TABLE 7 (continued)

Well Type	Drill Depth (m)	Sample Intake Elevation (m)	Well Size (cm)*
Site 4			
In-Refuse (IR)	7.6	419.2	10.2
Downstream Shallow (OS-X)	5.6	416.5	10.2
Observation (EX-1)	7.6	416.8	3.8
(EX-2)	3.5	416.3	"
Background (BG)	13.1	417.6	10.2
Site 5			
In-Refuse (IR)	11.3	28.0	10.2
Downstream Shallow (OS-1)	3.3	12.7	10.2
Background (BG)	19.8	53.6	10.2
Site 6			
In-Refuse (IR)	8.2	20.2	10.2
Downstream Shallow (OS-1)	4.6	14.7	10.2
Downstream Deep (OS-2)	8.5	11.3	10.2
Offsite, Phase II (OS-31)	17.4	17.0	6.4
(OS-32)		11.5	"
(OS-33)		3.0	"
Background (BG)	12.8	14.3	10.2
Site 7			
In-Refuse (IR)	10.7	265.7	10.2
Downstream Shallow (OS-1)	6.7	258.7	10.2
Downstream Deep (OS-2)	12.4	252.9	10.2
Observation (EX-1)	11.3	264.1	5.1
(EX-2)	13.7	268.4	"
(EX-3)	7.0	265.8	"
Offsite, Phase II (OS-3)	15.2	250.7	6.4[#]
Background (BG)	22.9	261.1	10.2
Site 8			
In-Refuse (IR)	3.0	198.3	5.1
Downstream Shallow (OS-1)	2.0	195.9	5.1
Downstream Deep (OS-2)	5.9	192.3	5.1
Observation (EX-1)	11.6	199.2	5.1
Offsite, Phase II (OS-3)	22.9	180.2	10.2
Background (BG)	9.8	204.8	10.2

* Well types of PVC material.

† A, C, and S are for aquifer , clay, and sand strata, respectively.

# Pneumatic sampler.

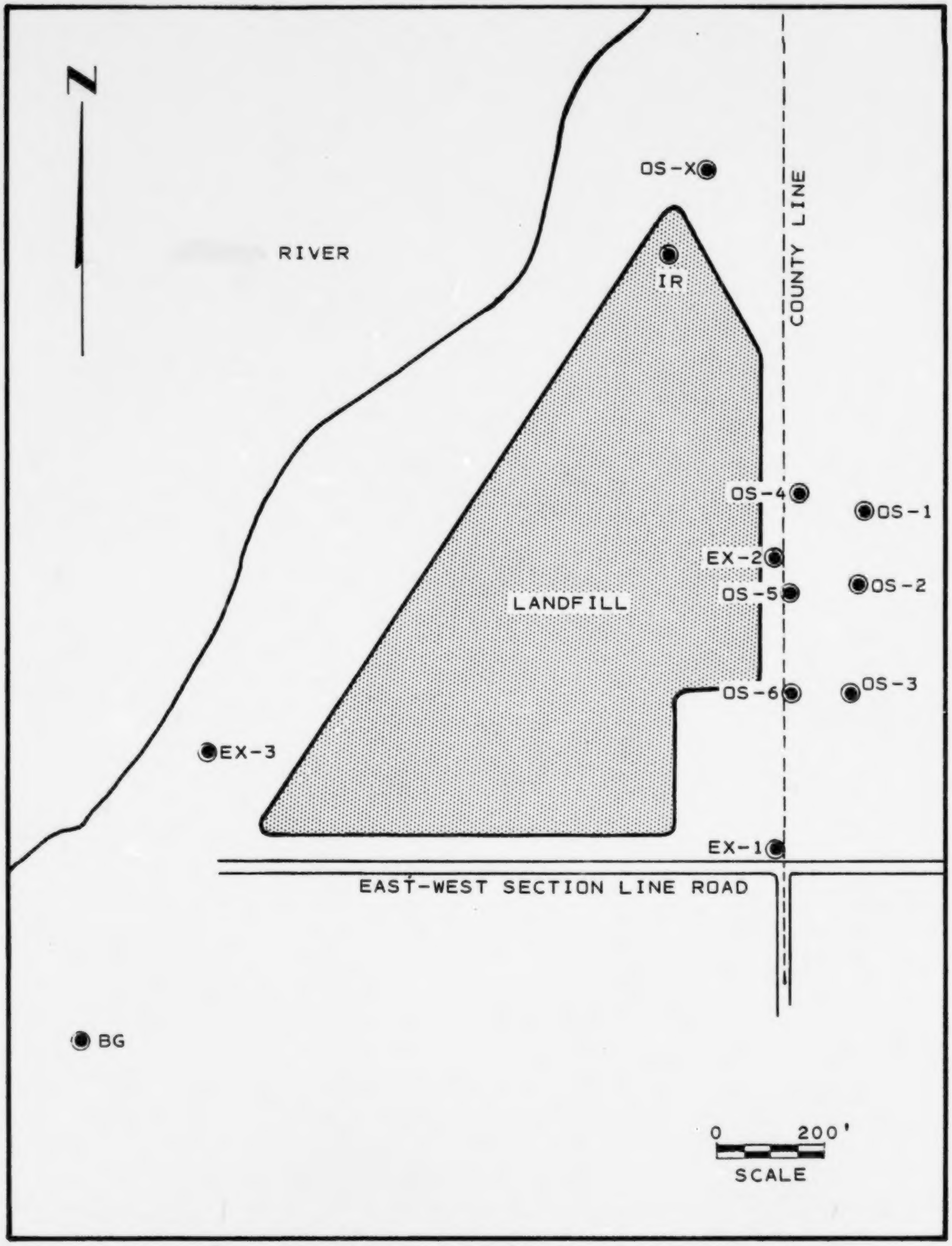

N
RIVER
OS-X
IR
COUNTY LINE
LANDFILL
OS-4
OS-1
EX-2
OS-5
OS-2
OS-6
OS-3
EX-3
EX-1
EAST-WEST SECTION LINE ROAD
BG
0
200'
SCALE

Figure 1. Locations of monitoring wells at site 1.

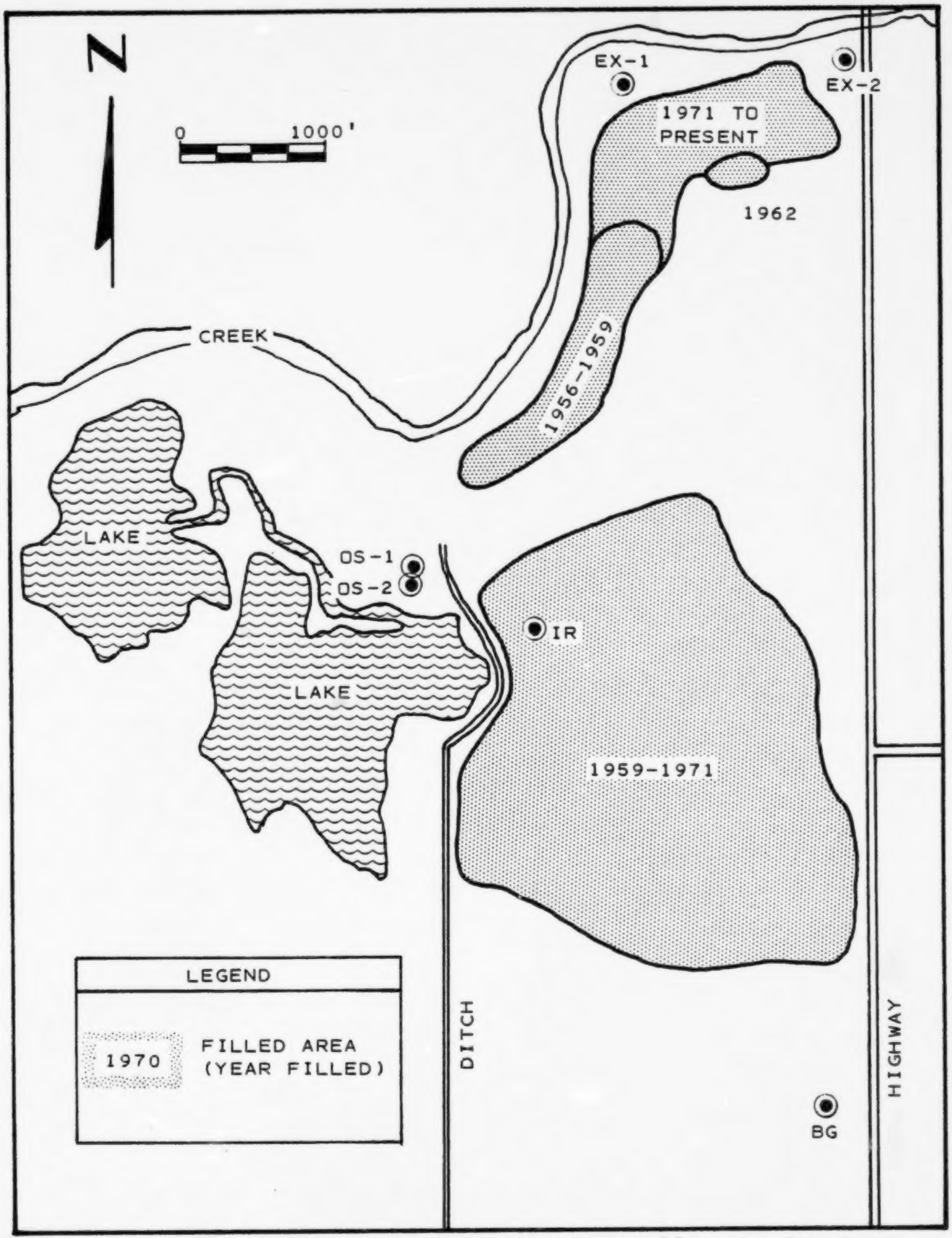

N
0
1000'
EX-1
EX-2
1971 TO PRESENT
1962
CREEK
1956-1959
LAKE
OS-1
OS-2
IR
LAKE
1959-1971
LEGEND
1970
FILLED AREA (YEAR FILLED)
DITCH
HIGHWAY
BG

Figure 2. Locations of monitoring wells at site 2.

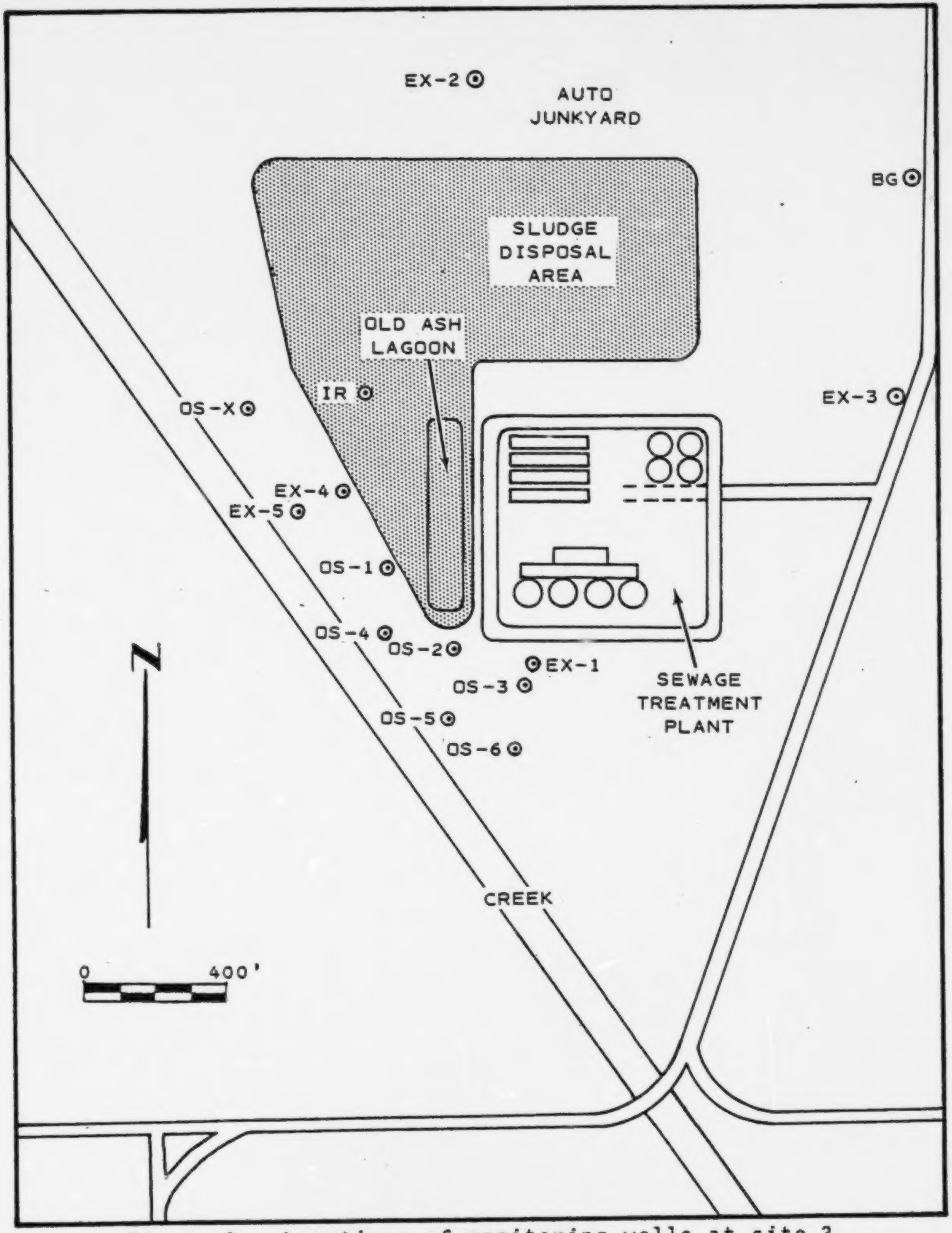

EX-2
AUTO JUNKYARD
BG
SLUDGE DISPOSAL AREA
OLD ASH LAGOON
IR
OS-X
EX-3
EX-4
EX-5
OS-1
OS-4
OS-2
EX-1
OS-3
SEWAGE TREATMENT PLANT
OS-5
OS-6
Z
CREEK
0
400'

Figure 3. Locations of monitoring wells at site 3.

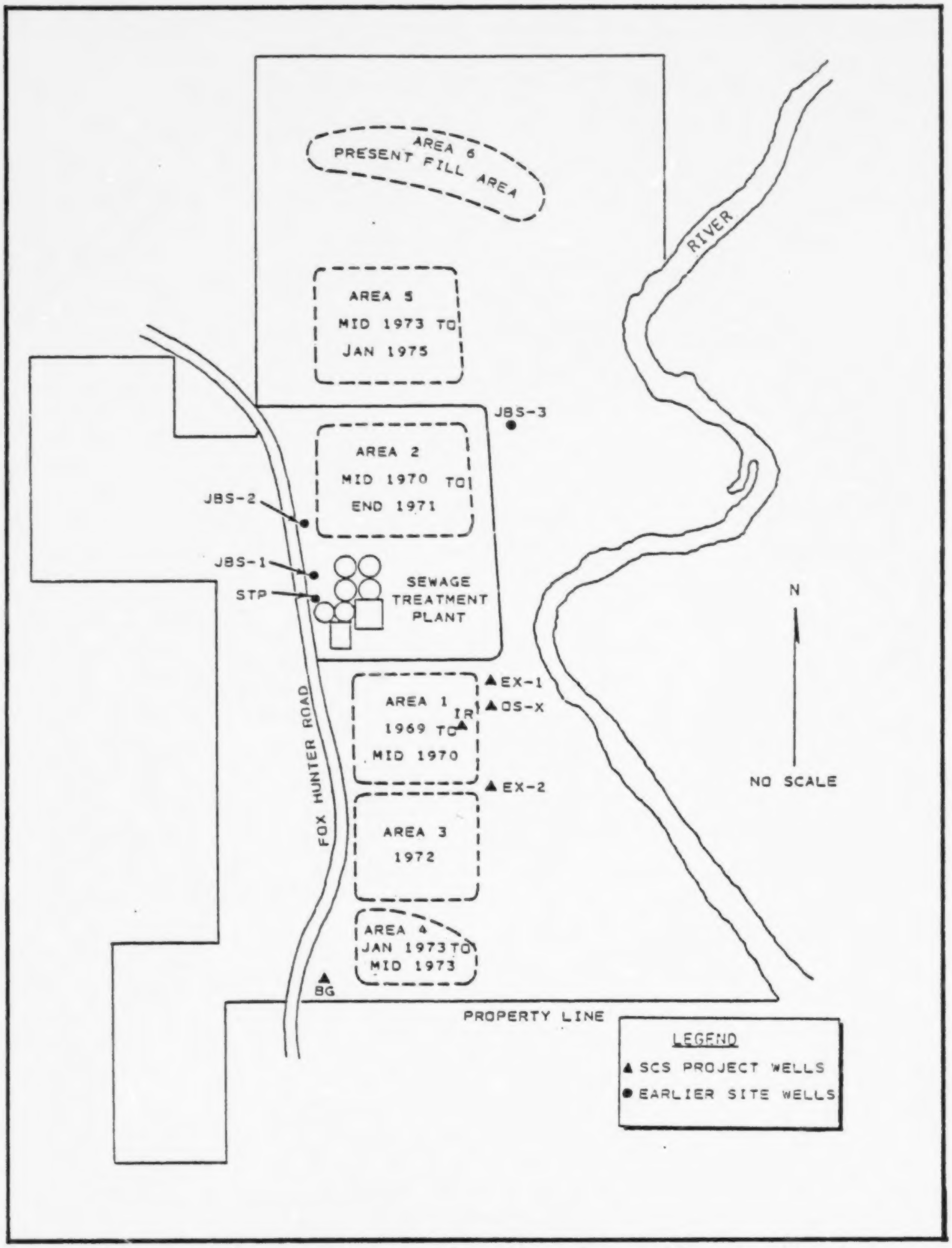

AREA 6
PRESENT FILL AREA
RIVER
AREA 5
MID 1973 TO
JAN 1975
JBS-3
AREA 2
MID 1970 TO
END 1971
JBS-2
JBS-1
STP
SEWAGE
TREATMENT
PLANT
N
▲ EX-1
▲ OS-X
IR
AREA 1
1969 TO
MID 1970
▲ EX-2
NO SCALE
FOX HUNTER ROAD
AREA 3
1972
AREA 4
JAN 1973 TO
MID 1973
BG
PROPERTY LINE
LEGEND
▲ SCS PROJECT WELLS
● EARLIER SITE WELLS

Figure 4. Locations of monitoring wells at site 4.

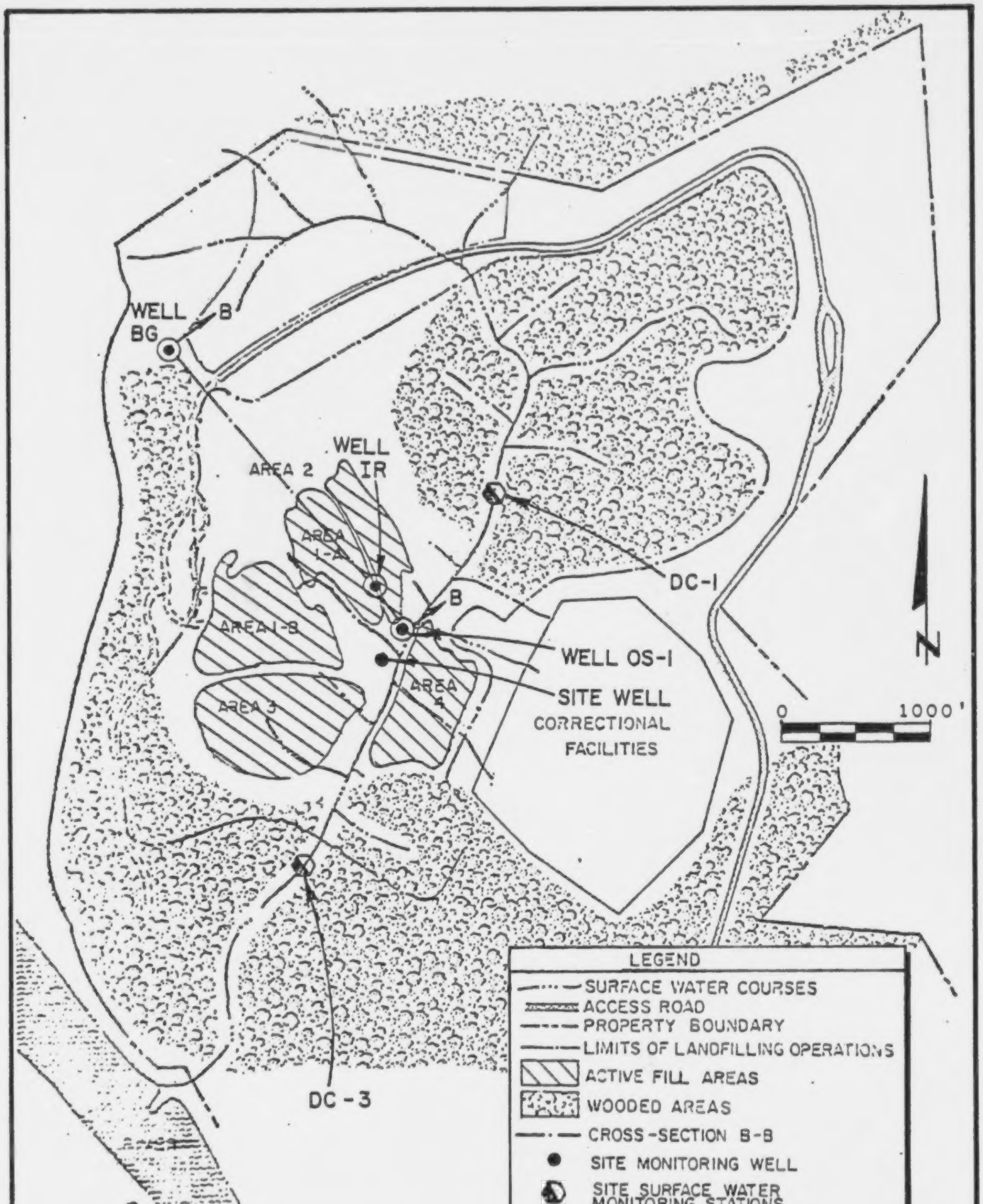

WELL BG
B
WELL IR
AREA 2
AREA 1-A
AREA 1-B
AREA 3
AREA 4
B
WELL OS-1
SITE WELL
CORRECTIONAL FACILITIES
DC-1
DC-3
N
0
1000'
LEGEND
SURFACE WATER COURSES
ACCESS ROAD
PROPERTY BOUNDARY
LIMITS OF LANDFILLING OPERATIONS
ACTIVE FILL AREAS
WOODED AREAS
CROSS-SECTION B-B
SITE MONITORING WELL
SITE SURFACE WATER MONITORING STATIONS
PROJECT MONITORING WELLS

Figure 5. Locations of monitoring wells at site 5.

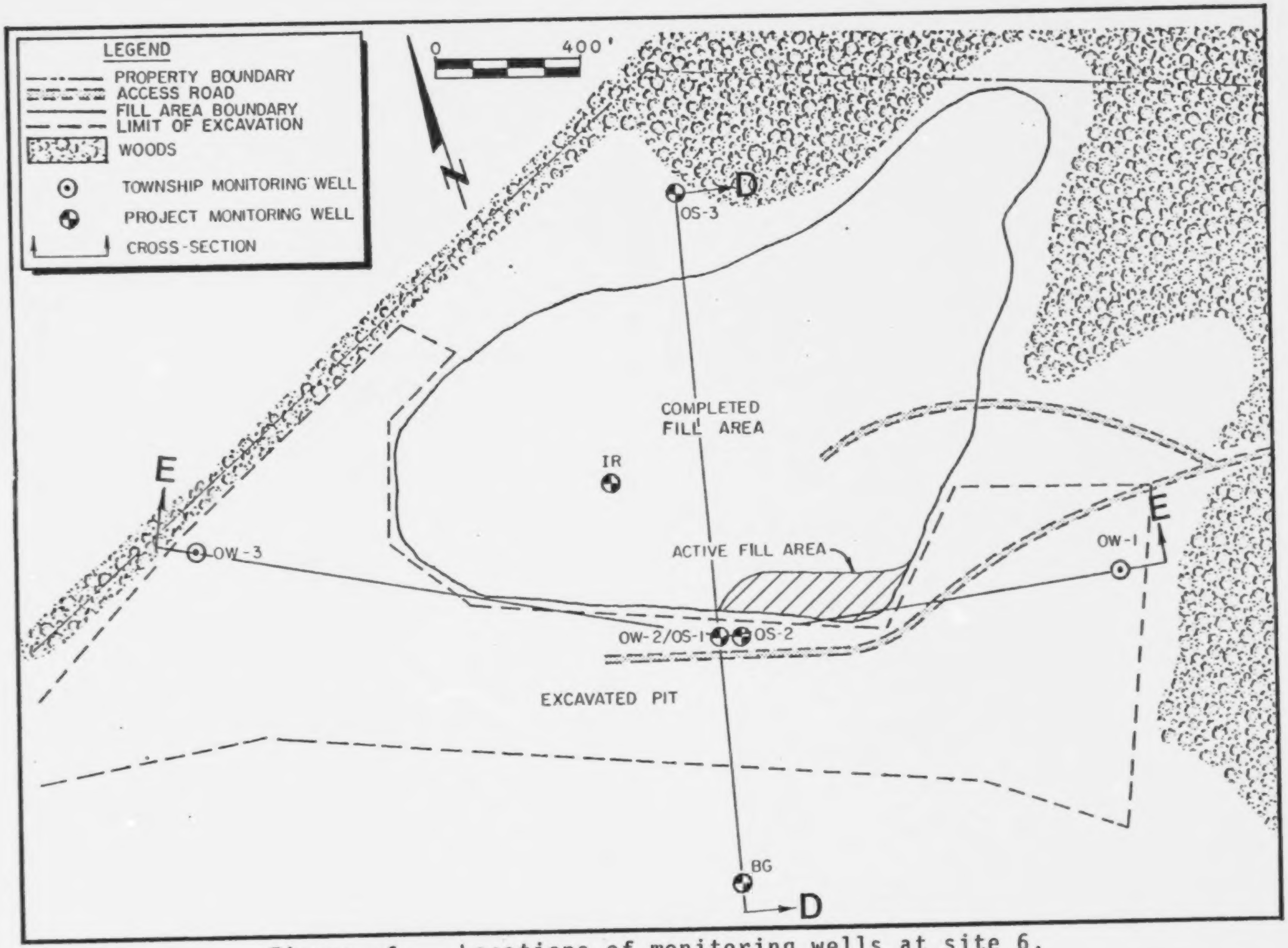

LEGEND
PROPERTY BOUNDARY
ACCESS ROAD
FILL AREA BOUNDARY
LIMIT OF EXCAVATION
WOODS
TOWNSHIP MONITORING WELL
PROJECT MONITORING WELL
CROSS-SECTION
0
400'
N
D
OS-3
COMPLETED FILL AREA
IR
E
OW-3
ACTIVE FILL AREA
OW-2/OS-1
OS-2
OW-1
E
EXCAVATED PIT
BG
D

Figure 6. Locations of monitoring wells at site 6.

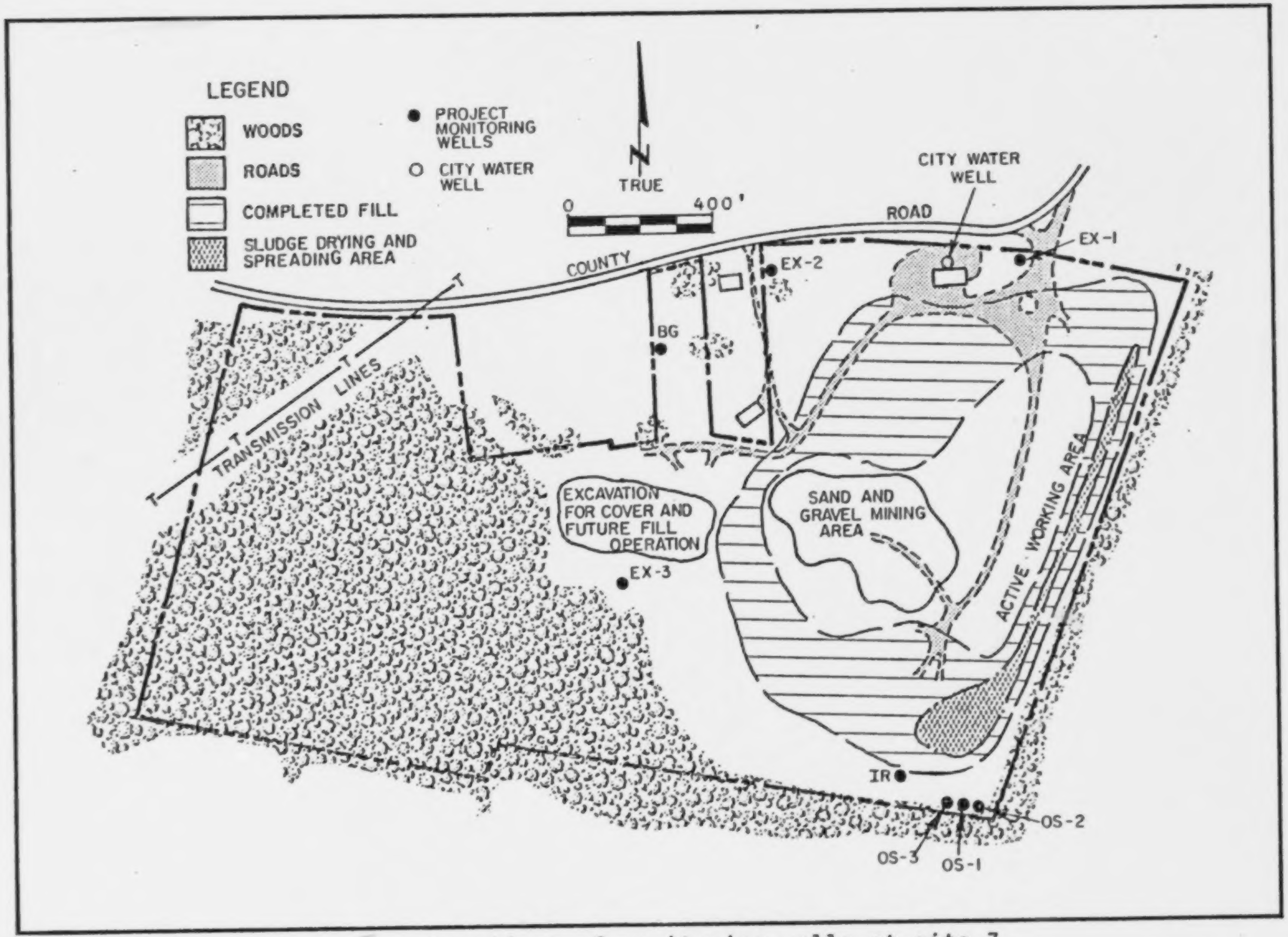

LEGEND
WOODS
ROADS
COMPLETED FILL
SLUDGE DRYING AND SPREADING AREA
● PROJECT MONITORING WELLS
○ CITY WATER WELL
TRUE
0
400'
COUNTY
ROAD
CITY WATER WELL
EX-1
EX-2
BG
TRANSMISSION LINES
T
EXCAVATION FOR COVER AND FUTURE FILL OPERATION
EX-3
SAND AND GRAVEL MINING AREA
ACTIVE WORKING AREA
IR
OS-2
OS-3
OS-1

Figure 7. Locations of monitoring wells at site 7.

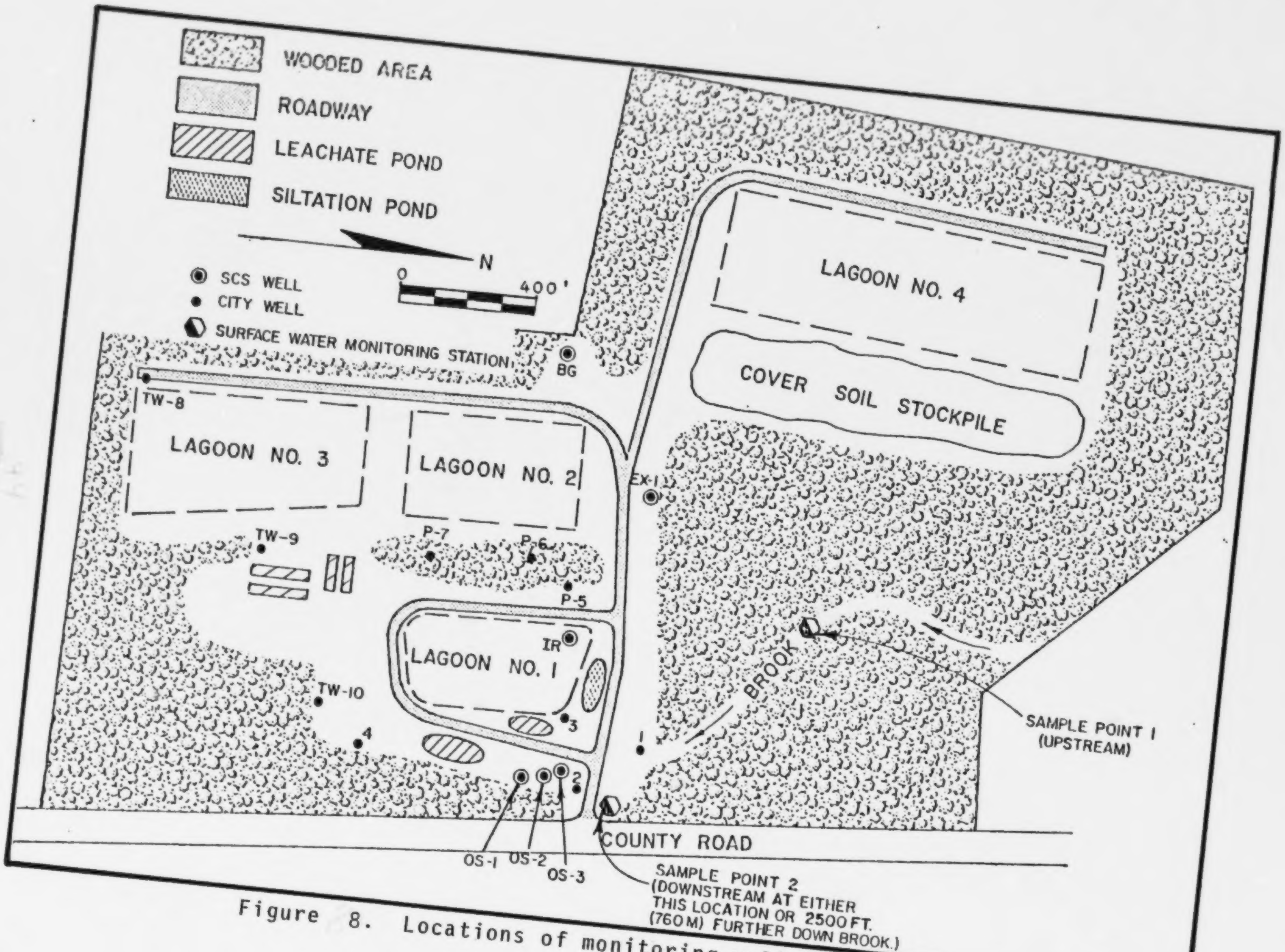

WOODED AREA
ROADWAY
LEACHATE POND
SILTATION POND
N
0
400'
SCS WELL
CITY WELL
SURFACE WATER MONITORING STATION
BG
TW-8
LAGOON NO. 3
LAGOON NO. 2
LAGOON NO. 4
COVER SOIL STOCKPILE
EX-1
TW-9
P-7
P-6
P-5
IR
LAGOON NO. 1
TW-10
4
3
2
1
BROOK
SAMPLE POINT 1 (UPSTREAM)
OS-1
OS-2
OS-3
COUNTY ROAD
SAMPLE POINT 2 (DOWNSTREAM AT EITHER THIS LOCATION OR 2500 FT. (760 M) FURTHER DOWN BROOK.)

Figure 8. Locations of monitoring wells at site 8.

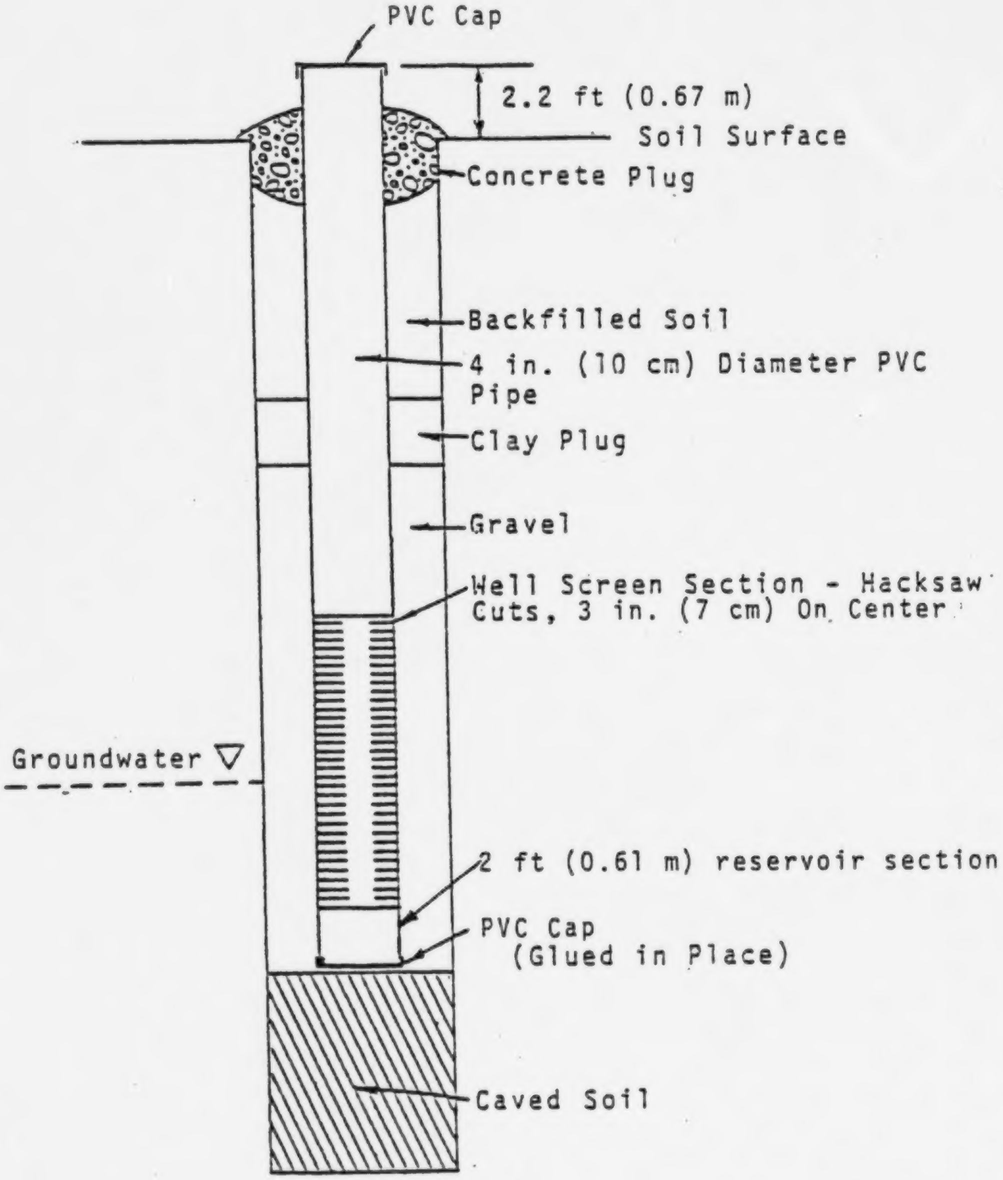

PVC Cap
2.2 ft (0.67 m)
Soil Surface
Concrete Plug
Backfilled Soil
4 in. (10 cm) Diameter PVC Pipe
Clay Plug
Gravel
Well Screen Section - Hacksaw Cuts, 3 in. (7 cm) On Center
Groundwater ∇
2 ft (0.61 m) reservoir section
PVC Cap (Glued in Place)
Caved Soil

Figure 9. Typical background well construction.

In-Refuse Well

An in-refuse well was installed within the landfill area in Phase I to monitor leachate and decomposition gases generated within proximity of the well. The well was drilled to groundwater, and a concrete plug placed between the groundwater table and bottom of the landfill. A 10.2-cm PVC pipe was then placed to approximately 0.5 m below the bottom of the landfill. Gas probes were placed at two depths, one approximately at 0.9 to 1.5 m below the surface (upper), and the other above the bottom (lower) of the landfill, on the outside of the well casing. A schematic of the in-refuse well is illustrated in Figure 10.

Off-Site Well

In Phase I, two downstream wells were installed approximately 31 to 92 m outside the limit of the disposal area in the presumed direction of groundwater flow. These wells were to intercept the groundwater passing the landfill. The shallow well would intercept the groundwater in the first meter or so of the aquifer. The deep well would penetrate a deeper stratum and intercept groundwater at a depth of about 6.1 m (site conditions permitting). The purpose was to detect differences in groundwater quality with depth.

The wells consisted of 10.2-cm PVC pipe extending to the desired depth. Because of bedrock, caving sand, or other impediments, deep wells were not dug at Sites 1, 3, 4, and 5. A schematic of the off-site wells is illustrated in Figure 11.

In Phase II, one additional deep well was installed at each of Sites 6, 7, and 8. They were 8.9, 2.8, and 17.0 m, respectively, deeper than the original deep wells at Sites 6, 7, and 8.

One major expansion in Phase II monitoring involved installation of six additional off-site wells with pneumatic, ejector-type sample collectors at Sites 1 and 3. The rationale behind the installation of these wells downstream of the disposal area was to establish the three-dimensional extent of the leachate plume emanating from the landfill (Figure 12). Two parallel lines, each containing three off-site wells with four sampling elevations within each well, were drawn perpendicular to the presumed central axis of the leachate plume at different distances from the disposal area. The two vertical planes passing through the leachate-contaminated groundwater enclave, coupled with the distinguishable direction of groundwater movement, defined a hypothetical leachate control volume (see Section 5).

As can be seen later, the orientation of the control volume was not truly perpendicular to the traverse central axis of the

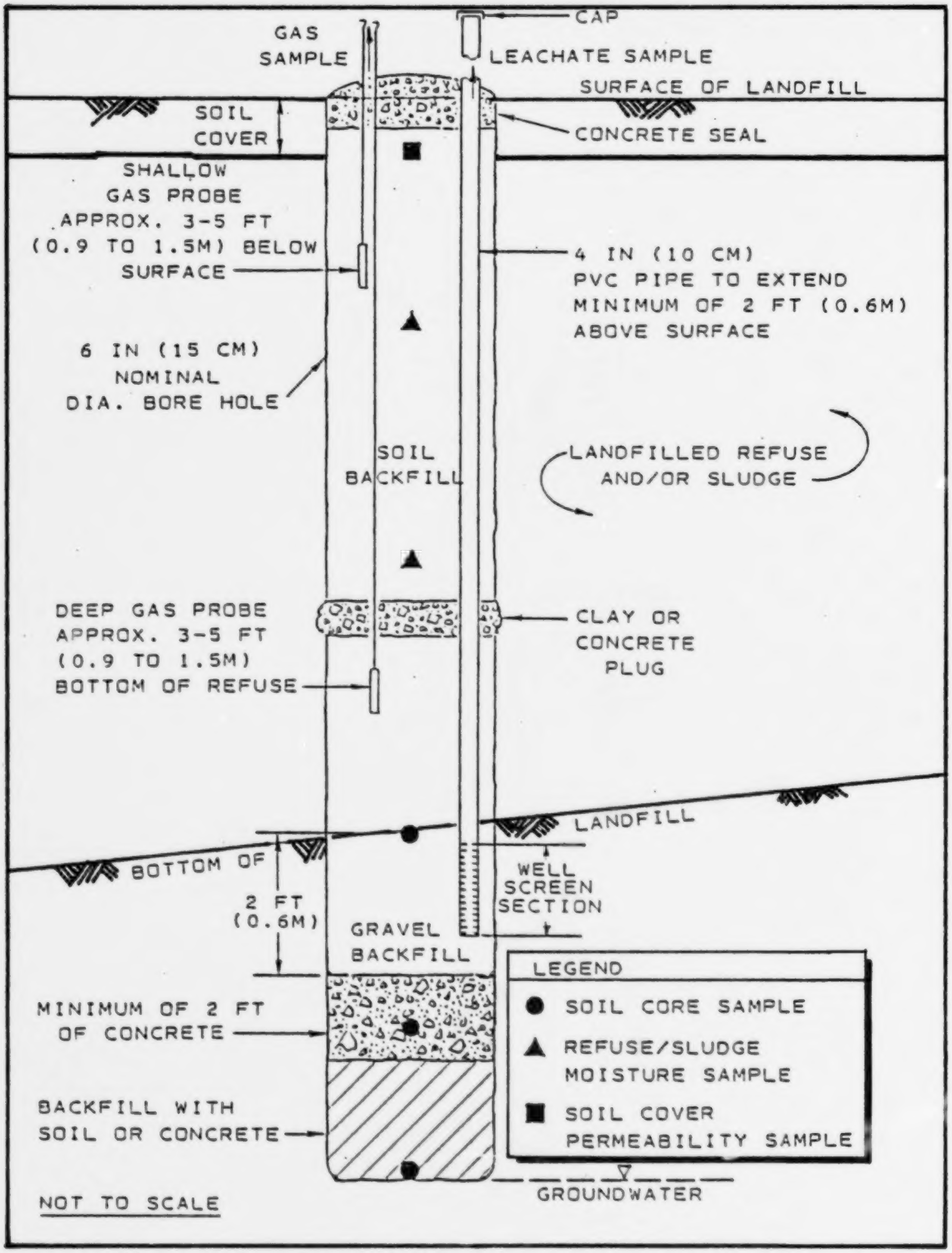

GAS SAMPLE
CAP
LEACHATE SAMPLE
SURFACE OF LANDFILL
SOIL COVER
CONCRETE SEAL
SHALLOW GAS PROBE APPROX. 3-5 FT (0.9 TO 1.5M) BELOW SURFACE
4 IN (10 CM) PVC PIPE TO EXTEND MINIMUM OF 2 FT (0.6M) ABOVE SURFACE
6 IN (15 CM) NOMINAL DIA. BORE HOLE
SOIL BACKFILL
LANDFILLED REFUSE AND/OR SLUDGE
DEEP GAS PROBE APPROX. 3-5 FT (0.9 TO 1.5M) BOTTOM OF REFUSE
CLAY OR CONCRETE PLUG
BOTTOM OF LANDFILL
2 FT (0.6M)
WELL SCREEN SECTION
GRAVEL BACKFILL
MINIMUM OF 2 FT OF CONCRETE
BACKFILL WITH SOIL OR CONCRETE
GROUNDWATER
LEGEND
● SOIL CORE SAMPLE
▲ REFUSE/SLUDGE MOISTURE SAMPLE
■ SOIL COVER PERMEABILITY SAMPLE
NOT TO SCALE

Figure 10. Typical in-refuse well construction.

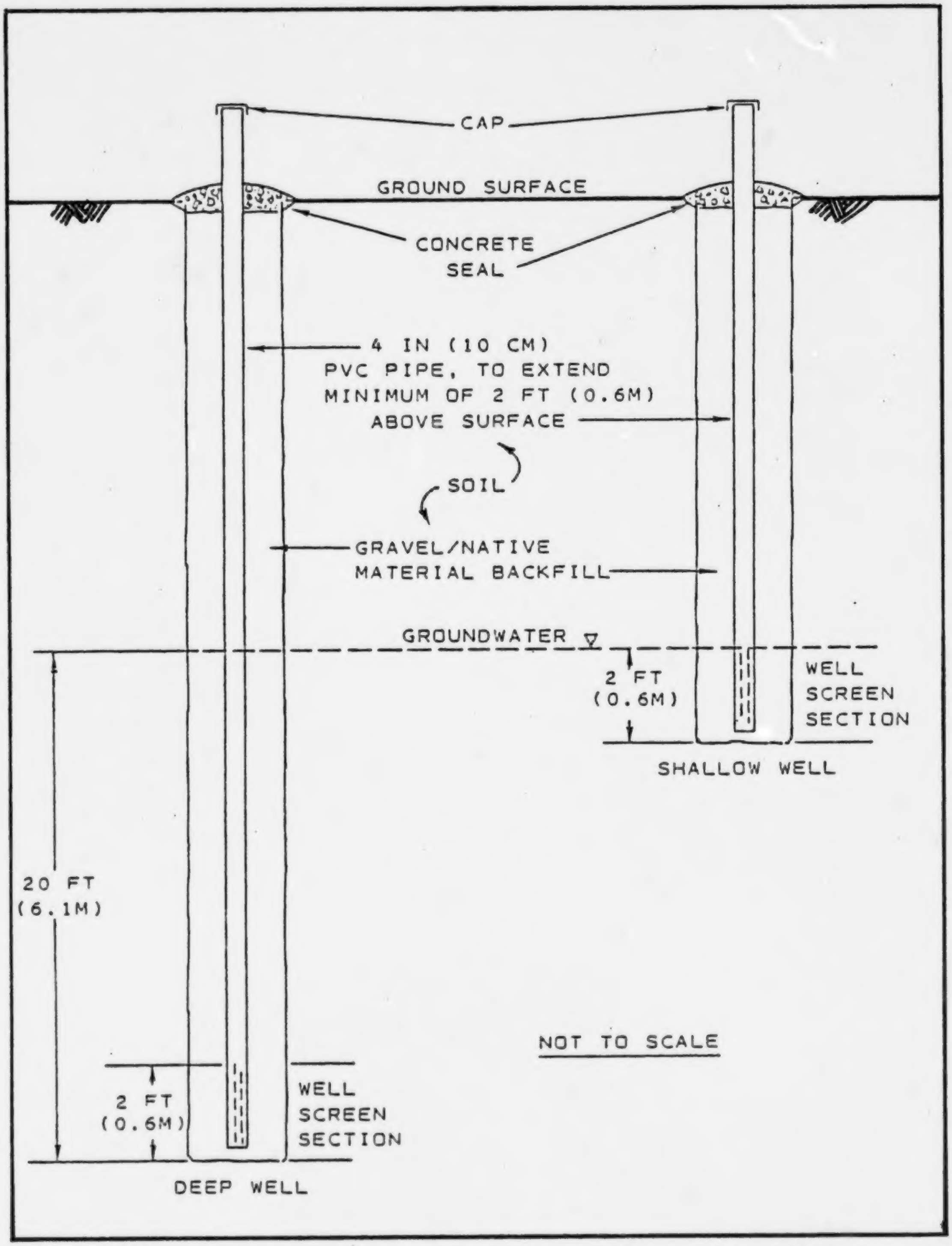

CAP
GROUND SURFACE
CONCRETE SEAL
4 IN (10 CM) PVC PIPE, TO EXTEND MINIMUM OF 2 FT (0.6M) ABOVE SURFACE
SOIL
GRAVEL/NATIVE MATERIAL BACKFILL
GROUNDWATER
2 FT (0.6M)
WELL SCREEN SECTION
SHALLOW WELL
20 FT (6.1M)
NOT TO SCALE
2 FT (0.6M)
WELL SCREEN SECTION
DEEP WELL

Figure 11. Typical downstream well construction.

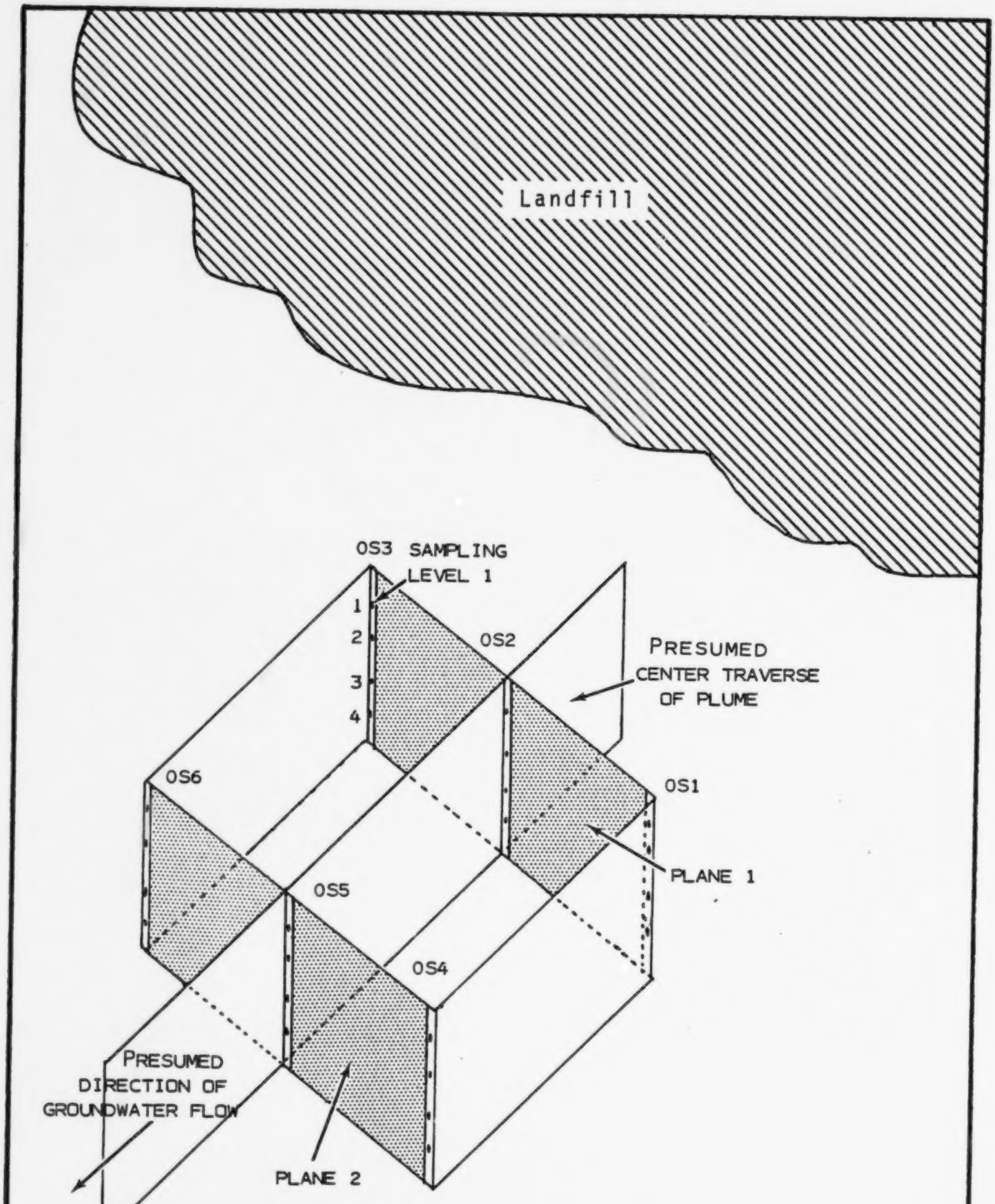

Landfill
OS3 SAMPLING LEVEL 1
1
2
3
4
OS2
PRESUMED CENTER TRAVERSE OF PLUME
OS6
OS1
OS5
PLANE 1
OS4
PRESUMED DIRECTION OF GROUNDWATER FLOW
PLANE 2

Figure 12 . Offsite well layout for Sites 1 and 3.

leachate plume. Adjustments were required for the shape and orientation of the control volume using the approximate direction of groundwater flow. As a result, the control volume was changed from a rectangular to a trapezoidal shape. Based on this shape, it is reasonably safe to assume that the plume for the designated cross section of groundwater flow passing through the first monitoring line was intercepted by the second line. However, due to various geologic formations, considerable variability in individual contaminant plume size, configuration, concentration strengths, and general location occurred with respect to the monitoring grid.

The control volume concept can be used to estimate total mass emission and the degree of attenuation or elution if all of the degrees of freedom in the independent equations are satisfied. The control volume represents a black box system for which a variety of independent and dependent equations may be written. One major factor to be considered is that sufficient monitoring time must be provided so that one can monitor a successive number of volumes of water or contaminants passing through the control volume. Without this, certain contaminants will have gotten an opportunity to enter the control volume but will not necessarily have had sufficient time to completely pass through it.

A schematic of the pneumatic, ejection type off-site well is illustrated in Figure 13. The well was constructed with four sampling levels separated by bentonite clay. A pneumatic sampler was installed at each sampling depth or level. This sampler consisted of a tube with a flap valve in the bottom and two tubes leaving the top that extended to the ground surface. Compressed nitrogen was introduced into one tube, which forces water from the sampler out the other tube to the surface where it was collected.

It is possible that the use of multiple depth sample probes in a single well may result in contamination of adjoining probes. The use of nested or multiple well bore holes with individual probes was preferable but not adopted because of cost and time considerations. Intuitively, if the probes were hydraulically connected in a common well hole, the leachate or contaminant concentrations at the four levels would appear to be of similar concentrations. However, examination of all of the Site 1 and Site 3 concentration isopleths revealed that this had not occurred.

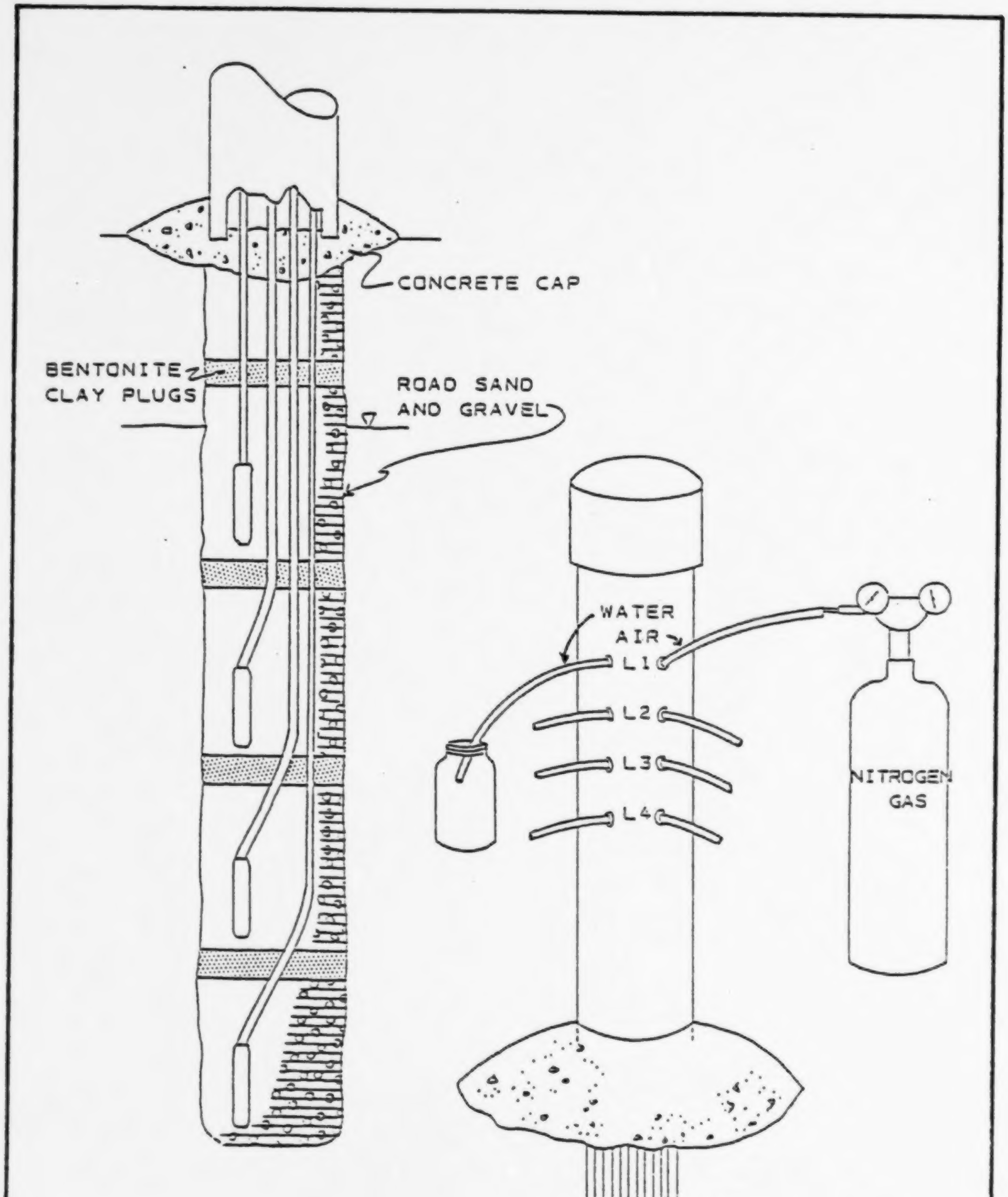

CONCRETE CAP
BENTONITE CLAY PLUGS
ROAD SAND AND GRAVEL
WATER
AIR
L1
L2
L3
L4
NITROGEN GAS

Figure 13. Typical plume well construction with pneumatic ejector samplers.

FIELD SAMPLING

Sampling of Waste, Soil, and Water

Phase I--

Grab sludge samples were obtained from the sewage treatment plant at each site at the beginning and toward the end of Phase I monitoring. At Site 2, the first sludge sample was taken from material excavated during placement of the in-refuse well.

Cover soil and core samples of soil were taken at the landfill bottom halfway between the landfill bottom and the groundwater table, and at the soil-groundwater interface. The core sample was sliced off from the sides and ends, and the center part was taken for chemical analysis. Due to the proximity of landfill bottom to groundwater table at Sites 1, 2, 3, 6, and 7, no sample was taken at the halfway mark from these sites.

At each site, groundwater samples from a nearby private well (background) and the off-site monitoring well(s) and leachate from the in-refuse well were sampled three times over a 4- to 6-mo period in 1975 and once more in June 1976. Gas samples were taken from each of the two gas probes placed in the in-refuse well.

Phase II--

During Phase II monitoring, following well installation, groundwater and leachate samples were taken bimonthly over a 1-yr period. Sludge and gas samples were not taken in Phase II. Soil samples obtained during drilling of the off-site wells were contaminated with soil material above the sampling depth; thus, no attempt was made to analyze these samples.

Detailed procedures for field sampling and preservation and shipping of samples are described in Appendix C.

CHEMICAL ANALYSIS

Soil, leachate, and groundwater samples collected in Phase I were analyzed for the same constituents. These constituents were:

- pH
- Total solids
- Ammonium-nitrogen
- Nitrate-nitrogen
- Total Kjeldahl nitrogen
- Chloride
- Sulfate
- Total organic carbon

- Chemical oxygen demand
- Calcium
- Cadmium
- Chromium
- Copper
- Iron
- Mercury
- Lead
- Zinc*
- Methylene blue-active substances (MBAS)*

Gas samples taken from the in-refuse wells during Phase I were analyzed for methane (CH_4), carbon dioxide (CO_2), oxygen (O_2), and nitrogen (N_2) contents.

In Phase II monitoring, the interest was primarily in heavy metals. Due to the large number of samples to be analyzed and costs involved, only the following constituents in leachate and groundwater samples were analyzed:

- Cadmium
- Chromium
- Copper
- Iron
- Mercury
- Nickel
- Lead
- Zinc
- Chloride
- Sulfate
- TOC
- Specific conductance.

In addition, water samples taken from the off-site wells at Sites 4, 7, and 8 during the fifth sampling period (Phase II) were examined for fecal coliform and fecal streptococcus. Prior to sample collection, the wells were disinfected by chlorination (free chlorine, >100 ppm) for 24 hr, followed by continuous pumping until no residual chlorine was detected. All sampling equipment was also disinfected by chlorination, whereas sample containers were disinfected by autoclaving in the laboratory. While pumping in the field, the sampling equipment was dechlorinated by flushing with well water until free of chlorine.

Detailed descriptions of sample preparation and analytical procedures employed are given in Appendix D.

---

*Determined in the June 1976 samples only.

ANALYTICAL QUALITY CONTROL

Detection Limits

Since state-of-the-art analytical detection limits for certain contaminants are close to the latest drinking water standards, acceptable detection limits and requisite accuracies for these threshold concentration ranges were needed. For this study, the requisite analytical sensitivities for the various contaminants in groundwater are given in Table 8. The minimum detection limits were established after comparing project requirements with drinking water standards approved and published in the December 24, 1975, Federal Register. The low and high end concentration accuracy requirements were based on equipment capabilities and typical state-of-the-art analytical procedures. These limits provided for the best possible laboratory work commercially available.

Quality Control

To ensure that the project laboratory was providing consistently reliable and accurate analytical results, two check samples* secured from EPA were submitted to the laboratory with each bimonthly batch of field samples. One check sample contained a high concentration and the other sample a low concentration of the constituents or elements to be analyzed simultaneously with the field samples. If the laboratory results exceeded the tolerable levels specified in Table 8 for any constituent(s), a rerun of an additional check sample submitted by EPA was required, as well as all field samples of that batch for the particular constituent(s) that failed. In the course of this project, very few samples needed to be rerun; overall, the quality of the laboratory work was quite satisfactory.

---

*Prior to each sample period, a new high and low concentration check sample was prepared by diluting, in different proportions, heavy metal standard solutions provided by EPA. Occasionally, split check samples were analyzed by another laboratory to verify the dilution values. The check samples were disguised as regular groundwater samples when submitted to the project laboratory. Analytical results for these disguised check samples were then compared against known concentration values to see if they met the strict quality control tolerances.

TABLE 8 . REQUISITE ANALYTICAL SENSITIVITIES FOR THE SELECTED CONSTITUENTS IN GROUNDWATER

	Minimum Detection Limit (mg/l)	Low Level Concentration (mg/l)	High Level Concentration (mg/l)	Anticipated Accuracy in ppm and %
TOC	1.0	1 - 20	>20	*±2 ppm or ± 5%
Chloride	2.0	2 - 20	>20	*±2 ppm or ± 10%
Sulfate	2.0	2 - 50	>50	*±5 ppm or ± 10%
Cadmium	0.01	.01 - 0.1	0.1 - 0.5	*±.02 ppm or ± 10%
Extraction	0.001	.001 - 0.1	0.1 - 0.5	± 10%
Copper	0.01	.01 - 0.1	0.1 - 0.5	*±.02 ppm or ± 10%
Chromium	0.02	.02 - 0.1	0.1 - 0.5	*±.025 ppm or ± 15%
Iron	0.01	.01 - 0.1	0.1 - 0.5	*±.03 ppm or ± 15%
Mercury (gas cell)	0.0002	.0002 - 0.005	>.005	*±.0004 ppm or ± 15%
Nickel	0.01	.01 - 0.1	0.1 - 0.5	*±.02 ppm or ± 10%
Lead				
Extraction	0.005	.005 - 0.1	0.1 - 0.5	*±.02 ppm or ± 20%
Zinc	0.01	.01 - 0.1	0.1 - 0.5	*±.02 ppm or ± 10%

* Accuracy of test procesures will be based on the higher of the given values.

SECTION 5

SPECIAL CONTROL VOLUME ANALYSES

APPROACH

All groundwater flow is three dimensional to some extent. If it were possible to measure the velocity of a water particle percolating through the soil and to represent velocity by a vector with a length proportional to velocity and parallel to the direction of flow, the vectors at any number of points along the flow path would not be coplanar. The degree of difficulty in solving groundwater problems depends on the extent to which flow is three dimensional. A three-dimensional groundwater flow problem can be dramatically simplified when symmetry features make it possible to assume a two-dimensional form.

In this study, special control volume analyses were used to solve the complex groundwater flow and groundwater quality problems. The special control volume consists of a three-dimensional monitored section perpendicular to the longitudinal axis of the presumed downstream leachate plume (Figure 14). Two vertical planes containing three monitoring wells each, and having four sampling elevations within each well, were placed perpendicular to the central axis of the leachate plume at varying distances from the disposal area. The two vertical planes passing through the leachate contaminated groundwater enclave, coupled with the distinguishable faces formed by the flow direction, form a hypothetical leachate control volume. In this special control volume approach, the groundwater flow was simplified to a two-dimensional flow: horizontal flow and vertical flow.

Any realistic modeling effort for solving complex groundwater flow, as well as groundwater quality problems, requires some sort of simplifying assumptions to bridge the gap between reality, our current understanding of the actual system, and practicability. Following are several general assumptions used for this study:

- The soil medium is homogeneous within any stratum studied.

- The liquid flow and porous material form a continuous system.

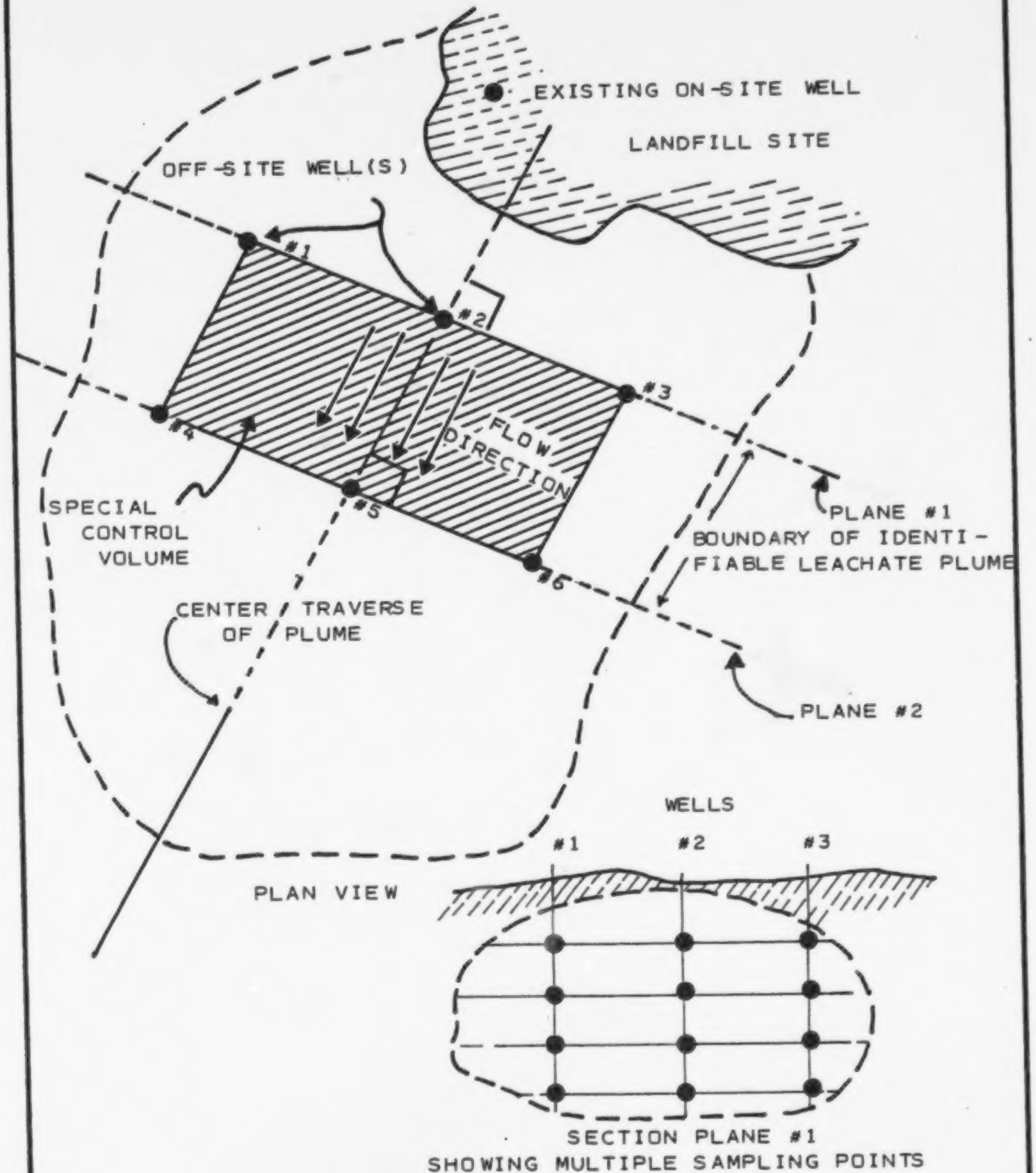

EXISTING ON-SITE WELL
LANDFILL SITE
OFF-SITE WELL(S)
#1
#2
#3
#4
#5
#6
FLOW DIRECTION
SPECIAL CONTROL VOLUME
CENTER TRAVERSE OF PLUME
PLANE #1
BOUNDARY OF IDENTIFIABLE LEACHATE PLUME
PLANE #2
PLAN VIEW
WELLS
#1
#2
#3
SECTION PLANE #1
SHOWING MULTIPLE SAMPLING POINTS

Figure 14. Illustration of field well layout.

- The flow is saturated in the pore space of the control volume.

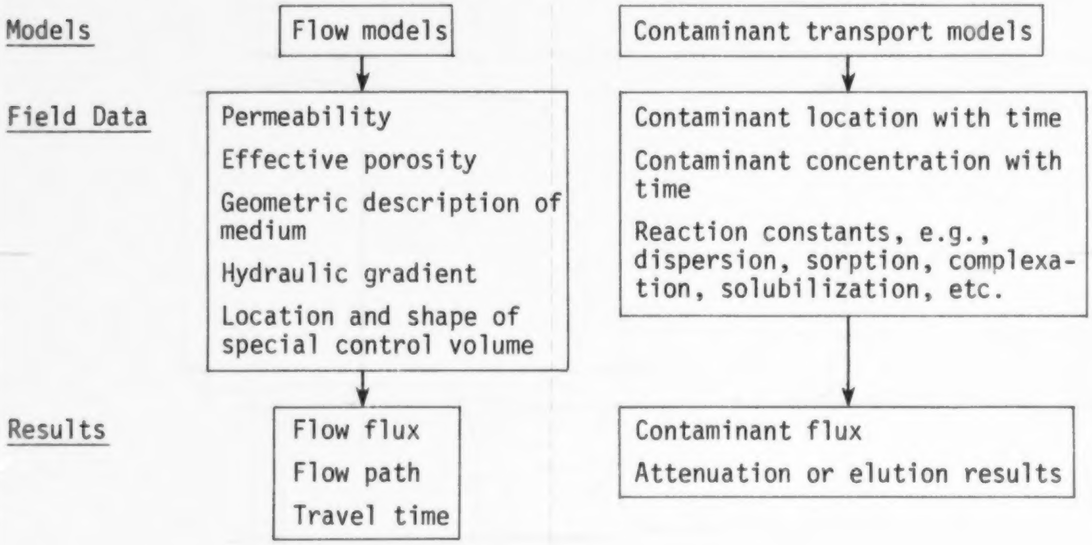
- The flow regime is laminar.

- The transport of constituents through a porous medium causes no significant changes in the porous material.

Two types of models will be used in this special control volume analyses:

- Flow models
- Contaminant transport models.

The sequence of events that occurs in modeling the system is illustrated in the following diagram:



Models
Flow models
Contaminant transport models
Field Data
Permeability
Effective porosity
Geometric description of medium
Hydraulic gradient
Location and shape of special control volume
Contaminant location with time
Contaminant concentration with time
Reaction constants, e.g., dispersion, sorption, complexation, solubilization, etc.
Results
Flow flux
Flow path
Travel time
Contaminant flux
Attenuation or elution results

MODELING

Flow Models

In this control volume analysis, input or output flows through different soil layers of the control volume are separated into two components: a horizontal flow component perpendicular to the upstream face of the control volume (Figure 15) and a vertical flow component, usually downward, and perpendicular to the horizontal. The flow velocity and flow rate can be solved by applying Darcy's law:

$$\overline{V}_H = KS_H \qquad (1)$$

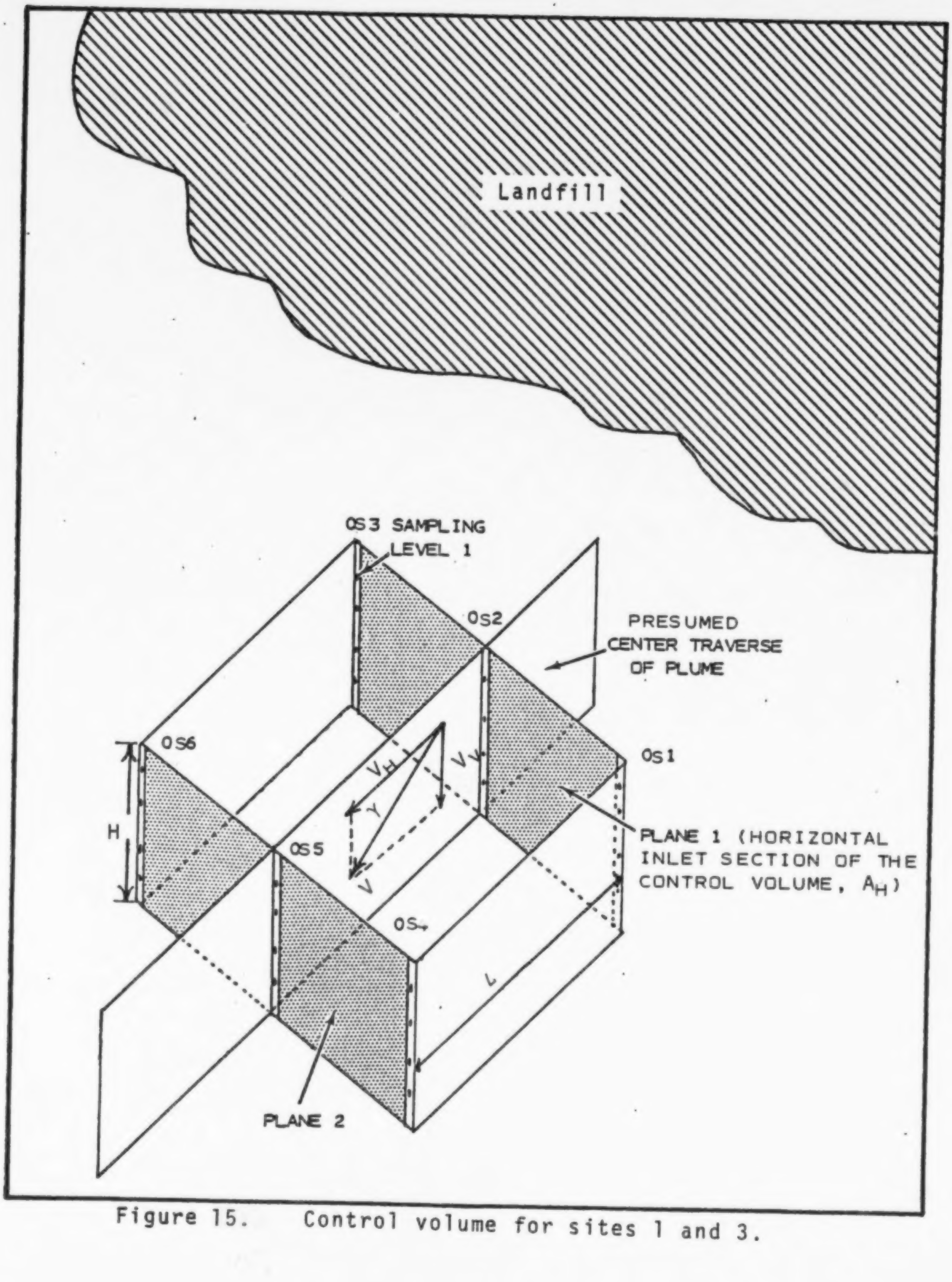

Landfill
OS3 SAMPLING LEVEL 1
OS2
PRESUMED CENTER TRAVERSE OF PLUME
OS6
V_H
V_V
OS1
H
γ
V
OS5
PLANE 1 (HORIZONTAL INLET SECTION OF THE CONTROL VOLUME, A_H)
OS4
L
PLANE 2

Figure 15. Control volume for sites 1 and 3.

$$\overline{V}_V = KS_V \tag{2}$$

$$Q_H = A_H \cdot \overline{V}_H \tag{3}$$

$$Q_V = A_V \cdot \overline{V}_V \tag{4}$$

$$V_H = \overline{V}_H/n \tag{5}$$

$$V_V = \overline{V}_V/n \tag{6}$$

Where $\overline{V}_H$ = horizontal specific discharge perpendicular to inlet section A_H

$\overline{V}_V$ = vertical specific discharge perpendicular to inlet section A_V (▱ OS1-OS2-OS3-OS4)

K = permeability (hydraulic conductivity)

S_H = hydraulic gradient (horizontal)

S_V = hydraulic gradient (vertical)

n = porosity

Q_H = horizontal flow rate

Q_V = vertical flow rate

V_H = true horizontal flow velocity perpendicular to inlet section A_H

V_V = true vertical flow velocity perpendicular to inlet section A_V.

Therefore, the flow direction and magnitude also can be solved by using

$$\tan \gamma = \frac{V_V}{V_H} \tag{7}$$

$$V = \sqrt{V_V^2 + V_H^2} \tag{8}$$

Where γ = the angle between the velocity vector and the horizontal plane.

Darcy's law is only applicable for the laminar flow range where resistive forces govern. As velocity increases, inertial forces and ultimately turbulent flows cause deviations from the linear relation. The flow rates in this study were low enough so that Darcy's law could be applied. True Darcian flow may also not occur in fine textured materials because of interferences by clay particles and their absorptive fields that attract water, causing it to be more static and not as free for movement. However, approximate flow velocities were calculated using this law.

Soil borings revealed numerous stratified layers within the control volume. This phenomenon is believed to greatly affect the direction and magnitude of the groundwater flow due to differences in soil layer permeability and hydraulic gradient. Under saturated flow conditions (Figure 16), a refraction of streamlines occurs when streamlines from a medium of permeability (K_1) cross the boundary of a medium with different permeability (K_2). Consider a stream tube composed of streamlines passing through A and B (Figure 16). By continuity, all the fluid flowing between those streamlines in Layer I also crosses into Layer II and remains between the refracted streamlines. In other words, the normal components of the average velocities on both sides of the boundary must be the same:

$$V_{1,n} = V_{2,n} \tag{9}$$

This can be expressed as

$$K_1 \frac{(\Delta h_1)_{AB}}{C_1B} \cos \Theta_1 = K_2 \frac{(\Delta h_2)_{AB}}{AC_2} \cos \Theta_2 \tag{10}$$

and

$$(\Delta h_1)_{AB} = (\Delta h_2)_{AB} \tag{11}$$

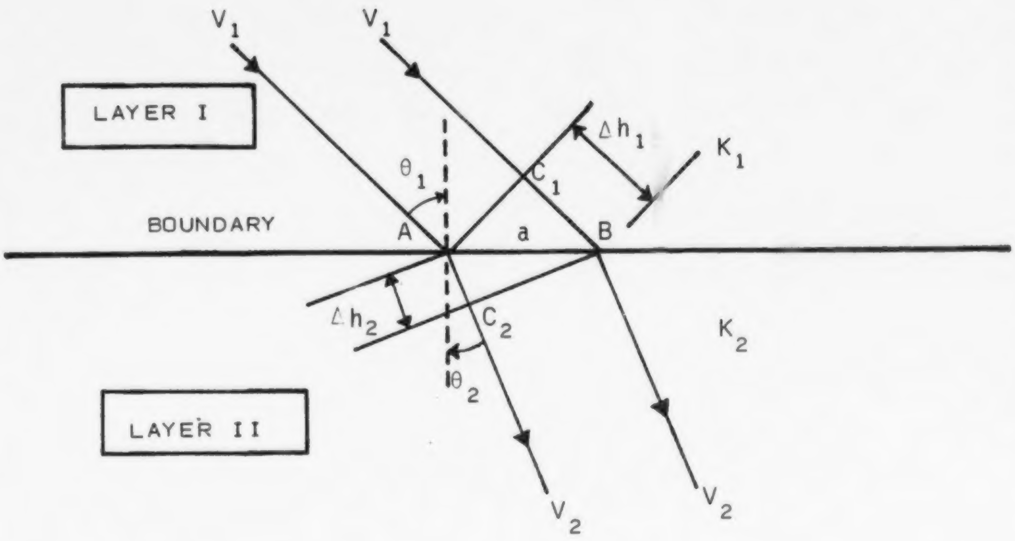
$$C_1B = a.\sin \Theta_1 \tag{12}$$

$$AC_2 = a.\sin \Theta_2 \tag{13}$$

Substituting Equations 11, 12, and 13 into Equation 10, the result is

$$\frac{\tan \Theta_1}{\tan \Theta_2} = \frac{K_1}{K_2} \tag{14}$$

This relationship shows that the change in flow path from one layer to another is related to the ratio of permeabilities between these two layers. If there are n horizontal layers of soil with thickness e_1, e_2, ... e_n, and the corresponding head



V_1
V_1
LAYER I
Δh_1
K_1
θ_1
C_1
BOUNDARY
A
a
B
Δh_2
C_2
K_2
θ_2
LAYER II
V_2
V_2

Figure 16. Refraction of streamlines across a boundary of different permeabilities.

loss is Δh_1, Δh_2, ... Δh_n, then the vertical flow rate may be expressed as

$$Q_V = A_V \cdot \frac{\Delta h_1}{e_1} \cdot K_1 = A_V \cdot \frac{\Delta h_2}{e_2} \cdot K_2 = \ldots \tag{15}$$

$$= A_V \cdot \frac{\Delta h_n}{e_n} \cdot K_n$$

The total head loss across the multilayered stratum will be

$$\sum_1^n \Delta h_n = \Delta h_1 + \Delta h_2 + \ldots + \Delta h_n$$

$$= \frac{Q_V}{A_V} \left(\frac{e_1}{K_1} + \frac{e_2}{K_2} + \frac{e_n}{K_n}\right) \tag{16}$$

Assume the overall permeability is K_V. Then

$$K_V = \frac{Q_V}{A_V} \left(\frac{H}{\sum_1^n \Delta h_n}\right) \tag{17}$$

where $H = e_1 + e_2 \ldots + e_n = \sum_1^n e_n$

$$\text{Therefore, } K_V = \frac{\sum_1^n e_n}{\sum_1^n \frac{e_n}{K_n}} \tag{18}$$

The vertical specific discharge crossing many layers of soil can then be solved as follows:

$$\overline{V}_V = K_V \cdot \frac{\sum_1^n \Delta h_n}{\sum_1^n e_n}$$

$$= \frac{\sum_1^n \Delta h_n}{\sum_1^n \frac{e_n}{K_n}}.$$

The specific discharge in nonhorizontal or nonvertical parallel layers can be solved using the relationships in Equations 14 and 19 and the inclined angle of these parallel layers:

$$\overline{V}_n = \frac{\sum_{1}^{n} \Delta h_n}{\sum_{1}^{n} \frac{e_n}{K_n}} \tag{20}$$

$$\overline{V}_V = \overline{V}_n \sin \gamma \tag{21}$$

$$\overline{V}_H = \overline{V}_n \cos \gamma \tag{22}$$

where γ is the inclined angle to the horizontal plane.

The true velocity can be derived by dividing the specific discharge by the porosity as shown before:

$$V_V = \overline{V}_V / n \tag{23}$$

$$V_H = \overline{V}_H / n \tag{24}$$

The overall travel time, t, crossing the boundaries of the control volume can be calculated by dividing the travel path, L, by the velocity:

$$t = \frac{L}{\sqrt{V_V^2 + V_H^2}} = \frac{L}{V} \tag{25}$$

In the above discussion, it was assumed that the flow direction was perpendicular to the inlet and outlet faces of the box-shaped control volume. (This assumption enables the flow to be partitioned into simple x and y coordinates.) Unfortunately, it was found during the 1-yr monitoring period that the direction of flow was not always perpendicular to the inlet face of the control volume. Therefore, a modification of the shape and dimensions of the control volume was necessary to solve the flow and contaminant transport problems. As shown in Figure 17, the following was assumed:

- The x-axis parallels the original leachate plume longitudinal axis (the perpendicular to the vertical inlet face of the original control volume).
- The y-axis is at right angles to the x-axis in the horizontal plane.

- The z-direction (downward) is normal to the x-y horizontal plane.

The piezometric elevations of the water table were measured at the exploratory wells to determine the changing hydraulic gradients referenced to the x, y, and z coordinate system. These measurements were then used to calculate the velocity components:

$$V_x = \frac{K \cdot S_x}{n} \tag{26}$$

$$V_y = \frac{K \cdot S_y}{n} \tag{27}$$

$$V_z = \frac{K \cdot S_z}{n} \tag{28}$$

Therefore,

$$V = \sqrt{{V_x}^2 + {V_y}^2 + {V_z}^2} \tag{29}$$

$$\Theta = \tan^{-1} \frac{V_z}{V_y} \tag{30}$$

$$\alpha = \tan^{-1} \frac{V_z}{V_y} \tag{31}$$

$$V_H = \frac{V_x}{\cos \Theta} \tag{32}$$

$$V_V = \frac{V_y}{\cos \alpha} \tag{33}$$

where V_H and V_V are velocity components in x-y and y-z planes, respectively, and Θ and α are the angles between $\overline{V}_H$ and the x-axis and $\overline{V}_V$ and the y-axis, respectively.

The shape of the control volume was reoriented from ▱ABEF to ▱ABCD, as shown in Figure 17, as dictated by the velocity vector V_H. This modification enables us to collect the same groundwater crossing both inlet and outlet boundaries and avoids reestimation of travel time, such as in ΔBCE where the horizontal travel time may range from zero to $\overline{BC}/V_H$. Similar modification of the vertical shape of the control volume was achieved by the same methods as shown above using the velocity vector.

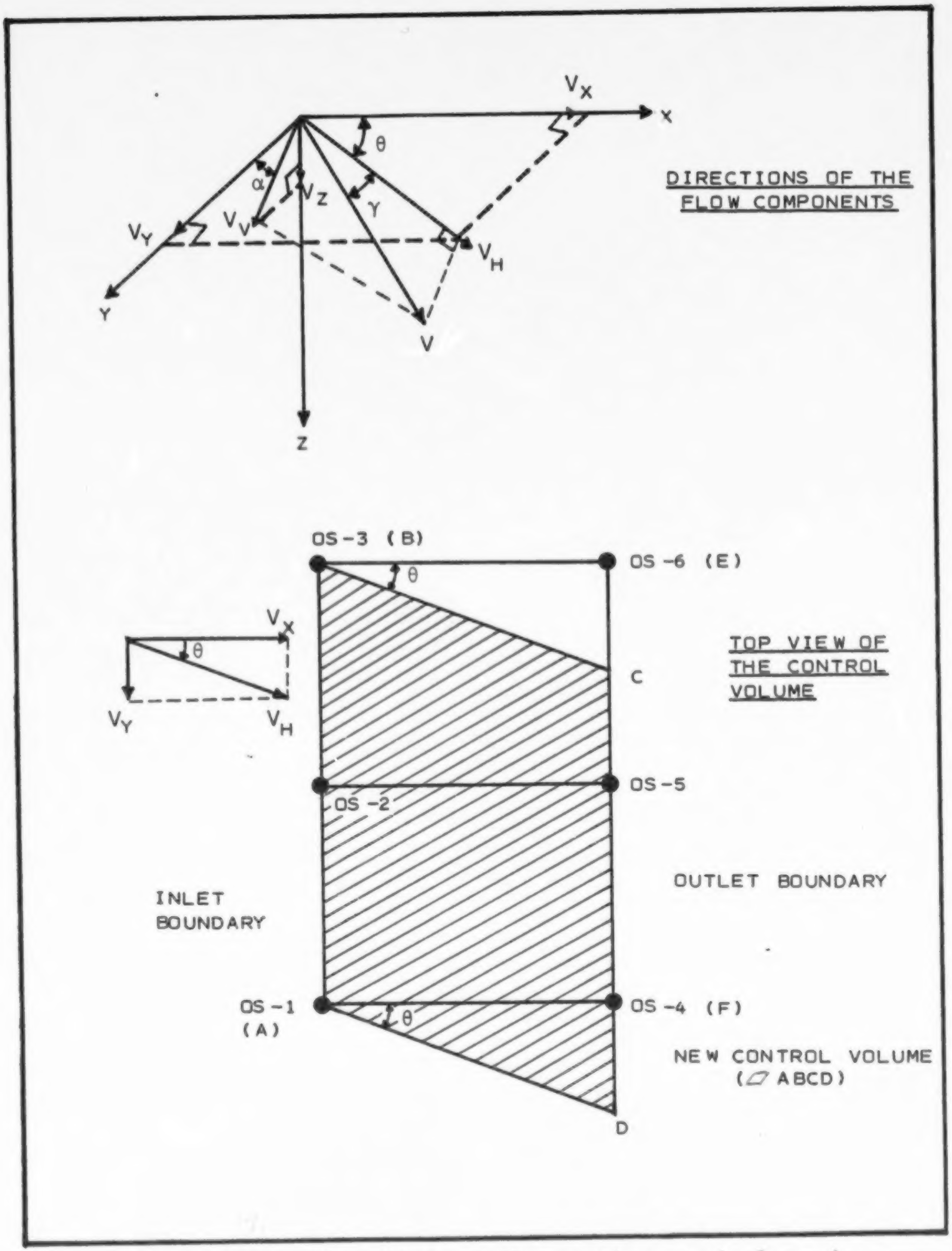

V_X
X
θ
α
V_Z
γ
DIRECTIONS OF THE FLOW COMPONENTS
V_Y
V_V
V_H
Y
V
Z
OS-3 (B)
θ
OS-6 (E)
V_X
θ
TOP VIEW OF THE CONTROL VOLUME
C
V_Y
V_H
OS-5
OS-2
OUTLET BOUNDARY
INLET BOUNDARY
OS-1 (A)
OS-4 (F)
θ
NEW CONTROL VOLUME (▱ ABCD)
D

Figure 17. Direction of flow vectors and plan view of reoriented control volume.

Contamination Flux and Attenuation of Contaminant

In the above discussion, it was assumed that the transport of constituents did not affect the fluid flow. However, many factors may cause differences in the movement of a groundwater fluid and the associated constituents. Examples of phenomena likely to cause such differences are ion exchange, sorption reaction, redox reaction, complexation, solubilization (dissolution and precipitation), bio-oxidation, and hydrodynamic dispersion. Since these soil-related physical, chemical, or biological mechanisms are usually highly complicated and quantitative information is usually unavailable, evaluation of the contaminant flux must be based on the mass balance over a certain fixed time period (molecular diffusion is assumed negligible).

The total mass flow rate (contaminant flux), J_t, of a contaminant through a small isoconcentration area, dA_t, and influent concentration, C_t, inlet section of the control volume at time t can be expressed as

$$J_t = \int_o^A C_t \cdot V_t \cdot dA_t \tag{34}$$

where A is the total inlet area of the control volume.

V_t is the flow velocity through the same isoconcentration area. The total input mass of a contaminant during time period T can be calculated from the above relation as follows:

Total Input Mass into Area A during Period T =

$$M_{in} = \int_o^T \int_o^A C_t \cdot V_t \cdot dA_t \cdot dt \tag{35}$$

The total mass input of a constituent into the inlet sections of the control volume corrected by the flow directions of V_H and V_V becomes:

$$M_{in} = M_{in,H} + M_{in,V} \tag{36}$$

and the total mass output from the control volume becomes

$$M_{out} = M_{out,H} + M_{out,V} \tag{37}$$

The attenuation or elution of a constituent through this special control volume can then be calculated from the combined mass balance Equations 36 and 37 as shown below:

$$M = M_{in} - M_{out} \tag{38}$$

The amount M indicates the total mass of a constituent changed by the soil(s) in the special control volume. The sign of M can be used for judging the transport direction of the constituent - a positive sign indicates that the constituent was attenuated by the soil media, while a negative sign indicates elution has occurred.

CALCULATIONS

The real situation observed during the course of this research was that the hydraulic gradients and subsequently the flow velocities and flow directions were constantly changing. It was also found that C_t and A_t were fluctuating widely with time (see concentration isopleths, Section 6). This phenomenon causes either the flow or contaminant transport models to be indeterminate due to insufficient information, e.g., sampling occurred six times for the entire experimental period of 318 days. Some rational assumptions were needed to be made so as to allow the calculations to proceed, such as:

- Changes of concentration vs time are linear between adjacent sample data points (Figure 18a)
- The hydraulic gradient is maintained constant for approximately a 2-mo period (approximately 1 mo before and after the actual sampling time)(Figure 18b).

Employing the above assumptions, Equation 35 can be simplified to summation form, as follows:

$$M = \sum_{n=1}^{n} C_n \cdot Q_n \cdot T_n \qquad (39)$$

and Equation 39 rearranged to:

$$M = \sum_{n=1}^{n} (C_n \cdot T_n)\, Q_n \qquad (40)$$

where $\Sigma\, C_n \cdot T_n$ is the area under the concentration-time curve, as shown in Figure 18a. To exercise Equation 40, Q_n, the product of specific discharge and cross sectional area, must be modified to account for the variable flow rates through the different soil strata encountered in the control volume. As is seen in the concentration isopleths (Section 6), the cross sectional area should be divided into many sub-areas conforming to areas of equal concentration (Figure 19a) to obtain accurate results. The changes in both specific discharge and control area make the calculation of Q_n extremely complicated, possibly necessitating the use of a computer. An alternative approach (Figure 19b) which is simple, easy to calculate, and a

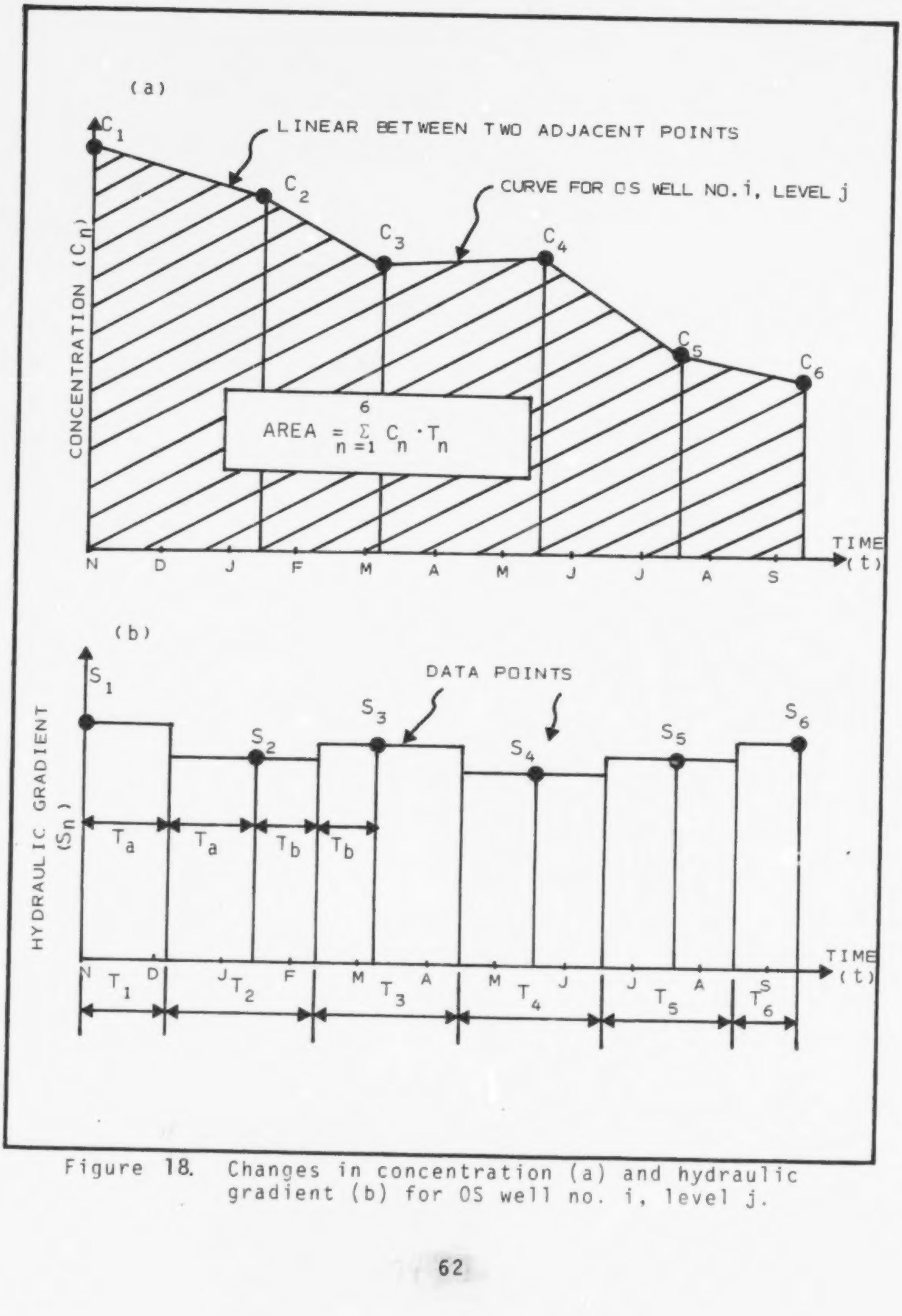

(a)
C_1
LINEAR BETWEEN TWO ADJACENT POINTS
C_2
CURVE FOR OS WELL NO. i, LEVEL j
C_3
C_4
C_5
C_6
CONCENTRATION (C_n)
AREA = $\sum_{n=1}^{6} C_n \cdot T_n$
N D J F M A M J J A S
TIME (t)
(b)
S_1
DATA POINTS
S_2
S_3
S_4
S_5
S_6
HYDRAULIC GRADIENT (S_n)
T_a T_a T_b T_b
N D J F M A M J J A S
T_1 T_2 T_3 T_4 T_5 T_6
TIME (t)

Figure 18. Changes in concentration (a) and hydraulic gradient (b) for OS well no. i, level j.

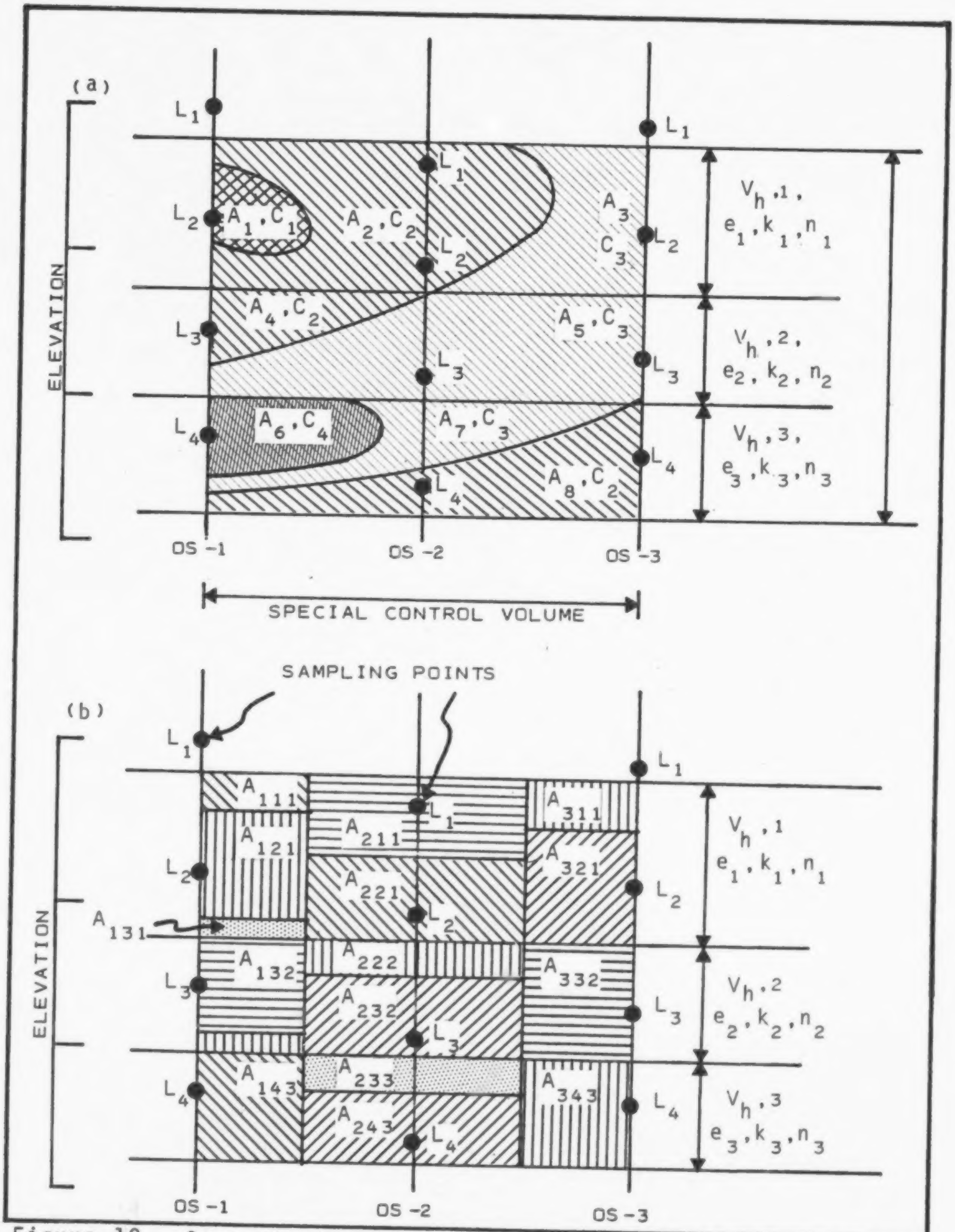

(a)
ELEVATION
L1
L2
L3
L4
A1, C1
A2, C2
A3, C3
A4, C2
A5, C3
A6, C4
A7, C3
A8, C2
Vh, 1, e1, k1, n1
Vh, 2, e2, k2, n2
Vh, 3, e3, k3, n3
OS -1
OS -2
OS -3
SPECIAL CONTROL VOLUME
SAMPLING POINTS
(b)
ELEVATION
A111
A121
A131
A132
A143
A211
A221
A222
A232
A233
A243
A311
A321
A332
A343

Figure 19. Concentration isopleth diagram (a) and partitioning of control volume face into subareas (b).

relatively close approximation to the former method, is to assume that the constituent concentration at any sampling point can be held constant halfway to the next sampling point in the same well or adjacent off-site well in the control volume. The small sub-areas, A_{ijk}, where i is the off-site well number, j the sampling point level, and k the type of soil, can be calculated as shown in Figure 19b.

Q_n can be solved by the following equation:

$$Q_{H,ijk} = A_{H,ijk} \cdot \overline{V}_{H,k} \tag{41}$$

$$Q_{V,ijk} = A_{V,ijk} \cdot \overline{V}_{V,k} \tag{42}$$

where $Q_{H,ijk}$ = horizontal flow rate through control face area $A_{H,ijk}$

$Q_{V,ijk}$ = vertical flow rate through control face area $A_{V,ijk}$

$\overline{V}_{H,k}$ = horizontal specific discharge in soil layer k

$\overline{V}_{V,k}$ = vertical specific discharge in soil layer k.

The contaminant flux of a constituent through control area A_{ijk} becomes:

$$J_{H,ijk} = C_{H,ijk} \cdot Q_{H,ijk} \tag{43}$$

$$J_{V,ijk} = C_{V,ijk} \cdot Q_{V,ijk} \tag{44}$$

Use of Equations 39 through 44 allow a materials balance type analysis to be made around the monitored control volume. However, in order to make sure the comparison is made on the same flow mass for the inflow and outflow, the time lag between passage from the inlet face to the outlet face should be taken into account.

(1) Calculate the travel time, T, between the inlet and outlet faces of the control volume both horizontally and vertically from:

$$T = \frac{L_H}{\overline{V}_H} = \frac{L_V}{\overline{V}_V} \tag{45}$$

where L_H and L_V are, respectively, the horizontal and vertical distances between the two faces.

(2) Chose the desired leaching period, T_p.

(3) Calculate the total inflow volume $\overline{V}$ for T_p.

(4) Choose starting values of C_{ijk} from concentration-time curves (Figure 18) for the outlet section after time period T.

(5) Calculate the time period, T_p', required for the outlet section to pass flow volume $\overline{V}$.

Values of T_p and T_p' are generally quite close, except when the shapes of the control area and the types of soil between the inlet and outlet boundaries vary. As will be shown in the next section for actual data, the deviation between T_p and T_p' for the Site 1 control volume was only 0.28 day.

The flow and contaminant transport models used in the analysis and interpretation of the Sites 1 and 3 control volume results are of necessity rough approximations to what actually occurred. The accuracy of the model and calculation results will be dependent on the accuracy of the assumptions (e.g., homogeneity of soil, fluctuation of flow and concentration of constituents, etc.). In the absence of additional off-site wells, more sampling points, greater frequency of sampling over a longer period of time, and more detailed information on the hydrogeology, some uncertainty is unavoidable. Nevertheless, trends and general impacts can be perceived from the data presented.

SECTION 6
DATA EVALUATION

INTRODUCTION

The monitoring program at each site included chemical analysis of soil, sludge, and decomposition gases during Phase I, and analysis of in-refuse well leachate and groundwater from background and downstream off-site wells in both phases of the study.

Soil samples taken during placement of in-refuse monitoring wells and sewage samples obtained from the sewage treatment plant were sequentially extracted with water and concentrated nitric acid for various selected constituents and contaminants. The portion extracted by water indicates possible solubility-controlling solids, the complexation species (salt effect), as well as some exchangeable ions. Presumably this water-soluble fraction is readily subjected to vertical and horizontal movement away from the landfill. The acid extraction is less defined. The results, however, may indicate concentrations of heavy metals in the noncrystalline form, which are immobile in the soil or sludge.

Cover soils taken at the eight disposal sites were measured for texture and horizontal and vertical permeability coefficients. Two or more cover soil samples were tested for permeability at several sites. These results were presented earlier in Section 3.

Gas samples taken from the in-refuse wells were analyzed for percentage by volume of methane, carbon dioxide, oxygen, and nitrogen.

Leachate from the in-refuse well and groundwater from background and various downstream wells was collected and analyzed for selected contaminants. During Phase I of this study, no background well was installed; thus, one or two grab samples were taken from an upstream domestic source, e.g., private well. Of four sampling dates, three covered a period of from 3 to 5 mo in 1975, while one was in June 1976. Based on these results and recommendations, a more extensive monitoring program was conducted that included installation of background and exploratory wells at all sites and additional downstream wells at Sites 1, 3, 6, 7, and 8. This Phase II sampling encompassed a period of 12 mo with six sampling dates. Tabulations of results are given in Tables 1 through 8 of Appendix E.

Results of groundwater analyses were compared with EPA drinking water standards to determine the extent of groundwater contamination.

The discussion of results for each site covers soil, sludge, leachate, decomposition gases, and groundwater, as well as environmental impact assessments. Sites 1 and 3 also include the control volume analysis for groundwater. In assessing the environmental impacts of landfilling sewage sludge, primary emphasis is placed on the evaluation of possible degradation of groundwater quality downstream from the disposal area.

SITE 1

Soil Analyses

Soil samples were taken from the refuse-soil interface (at 7.3 to 7.6 m) and the soil-groundwater interface (at 11.0 to 11.3 m) during drilling of the in-refuse well. These samples were extracted sequentially with water and nitric acid; the results are presented in Table 9.

The soil at the refuse-soil interface contained considerably higher concentrations of TOC, COD, chloride, and sulfate than the soil near the groundwater table, indicating both the impact of leachate and the strong attenuative capacity of the soil immediately below the fill. Nitrogen was primarily in the ammonium form in the soil near the fill; no nitrate was detected at either depth. A large proportion of the calcium present was in the water-soluble form. Heavy metals were found primarily in the acid extracts, except for iron; only traces of the water-soluble forms were detected. This would suggest that, despite slightly to moderately acidic soils (pH 5.8 and 6.7), migration of heavy metals in the soil was limited because of low water solubility. The heavy metal concentrations in the acid extracts were generally less than the concentrations commonly reported in soils (1, 2). The concentration of lead (18.2 and 13.2 ppm) was slightly greater than that commonly reported (10 ppm). This lead is probably background, although its origin cannot be determined from the data.

Sludge Analyses

The grab sludge samples obtained from the sewage treatment plant were extracted sequentially with water and concentrated nitric acid (Table 9). The July 1975 sample showed relatively high concentrations of COD, TKN, ammonium, and water-soluble calcium, chromium, copper, iron, and lead. The constituent concentrations were within the ranges, as reported by Sommers (9). Copper and iron concentrations in the June 1976 sample were greater than the median concentrations reported (9). Other heavy metals in water suggested a great potential for migration away from the disposal site.

TABLE 9. ANALYTICAL RESULTS FOR SITE 1, PHASE I*

	Soil Samples Taken Below Landfill During Drilling of In-Refuse Well			
	Refuse-Soil Interface (7.3 to 7.6 m)		Soil-Groundwater Interface (11 to 11.3 m)	
Constituent†	Water	Acid	Water	Acid
	6/26/75		6/26/75	
pH	5.8		6.7	
TOC	3440		88	
COD	7789		202	
TKN	132		108	
NH_4-N	111		7.4	
NO_3-N	<0.4		<0.4	
Cl	270		120	
SO_4	220		90	
Ca	1375	1900	75	1625
Cd	<0.03	0.17	<0.03	0.32
Cr	<0.30	3.21	<0.30	5.79
Cu	<0.20	5.37	<0.20	12.17
Fe	0.86	1692	1.71	7438
Hg	0.005	0.010	0.005	0.004
Pb	<0.20	18.2	<0.2	13.2

TABLE 9 (continued)

Constituent†	Sludge#				Background Groundwater	
	Water	Acid	Water	Acid		
	7/8/75		6/4/76		10/14/75	6/4/76
pH					7.6	
Tot. Solids					598.1	
TOC	50000		45360		14	2.0
COD	173056				17	
MBAS			<0.1			<0.01
TKN	7145				0.2	
NH_4-N	687				0.2	
NO_3-N	1.1				0.65	
Cl	110		12		24	27
SO_4	<10		88		152	240
Ca	1740				46	
Cd	0.77			1.5	<0.001	.001
Cr	10.17			53	<0.01	<.01
Cu	108			200	0.008	.01
Fe	187			2000	0.10	.23
Hg	0.087			<0.003	0.0008	<.0002
Ni				2.9		<.01
Pb	21.0			72	0.020	.007
Zn				212		.49

TABLE 9 (continued)

Constituent†	Offsite Well (Shallow)			
	7/8/75	9/18/75	10/14/75	6/4/76
pH	Insufficient sample	7.9		
Tot. Solids		609		
TOC		10	52	12
COD		30	83	
MBAS				0.04
TKN		1.1	2.7	
NH_4-N		0.14	1.3	
NO_3-N		<0.02	0.25	
Cl		25	47	36
SO_4		238	430	315
Ca		70	87	
Cd		0.008	0.003	0.001
Cr		<0.01	0.03	0.07
Cu		0.008	0.016	0.02
Fe		0.33	0.85	4.6
Hg		<0.0002	0.0004	<0.0002
Ni				0.02
Pb		0.056	0.035	0.02
Zn				0.09

* Soil and sludge were extracted with water and concentrated nitric acid. Sampling dates are also indicated.

† Concentrations are expressed as mg/kg of dry soil, mg/kg of wet sludge, mg/l of groundwater or leachate

# Moisture content for the 6/4/76 sample was 85 percent.

Leachate Analyses

The results of the leachate analyses are presented in Table 10; only one leachate sample was obtained in Phase I because of the dry well.

The leachates were characterized by the high levels of iron, zinc, TOC, and specific conductance and low to nondetectable levels of cadmium, chromium, copper, and mercury. Peak concentrations of most constituents generally occurred in the summer, probably as a result of high precipitation. Except for cadmium and chromium, the heavy metal concentrations in the leachate appeared to be correlated with TOC concentrations. The data suggested that the heavy metals in the leachate were moving in the form of metal-organic complexes.

Decomposition Gases in In-Refuse Well

Gas samples collected at two depths from the in-refuse well were analyzed for methane, carbon dioxide, oxygen, and nitrogen (Table 11). Generally, approximately 50 and 40 percent of the volume of the gas were methane and carbon dioxide, respectively, while oxygen and nitrogen were present in trace amounts. The volume composition of methane and carbon dioxide remained relatively constant regardless of sampling depth and date, indicating stability of the landfill.

Groundwater Analyses

During Phases I and II, groundwater samples were taken both upstream and downstream from the landfill. Phase I background groundwater samples were taken from a home near the landfill. This home well water received no additional treatment after being withdrawn from the ground. The Phase II background groundwater samples were from the project background well southwest of the landfill.

During Phase II, groundwater samples were taken from six new pneumatic type off-site wells and from the Phase I shallow off-site well (OS-X at 5.8 m). Analytical data for Phases I and II are presented in Table 9 and in Table 1 of Appendix E, respectively.

Background Groundwater--

Evaluation of Phase I background groundwater results shows that concentrations of total solids, TOC, COD, chloride, sulfate, and calcium, were in the ppm range, while other heavy metals and nitrogen compounds were in the sub-ppm range. These data were all well within the concentration ranges of most terrestrial waters (4).

TABLE 10. CHEMICAL ANALYSIS OF LEACHATES FROM IN-REFUSE WELL (SITE 1)

	Phase I[†]	Phase II[†]				
Constituent[*]	6/4/76	10/31/76	1/21/77	5/19/77	7/19/77	9/14/77
Cd	0.003	0.050	0.050	0.005	0.045	0.040
Cr	0.01	0.25	0.12	0.04	0.11	0.11
Cu	<0.01	0.13	0.11	0.02	0.13	0.09
Fe	190	800	1100	235	930	6.0
Hg	<0.0002	0.0002	<0.0002		<0.0002	<0.0002
Ni	0.04	0.48	0.37	0.24	0.48	0.30
Pb	0.10	0.060	0.700	0.140	1.280	0.680
Zn	11	1.2	32.0	3.2	95.0	66.0
Cl		--[#]	230	18	92	153
SO_4	8	--	85	--	150	17
TOC	985	--	14470	2600	10100	3780
Sp. Cond.		--	18000	--	17500	6900

---

[*] Specific conductance in µmhos/cm, all other constituent concentrations in ppm.

[†] Due to dry well, no samples were taken on 7/8/75, 9/18/75, 10/14/75 (Phase I) and 3/10/77 (Phase II).

[#] Insufficient sample.

TABLE 11. GAS COMPOSITION AT SITE 1 IN-REFUSE WELL

Gas Species	7/8/75 Upper	7/8/75 Lower	9/8/75 Upper	9/8/75 Lower	10/14/75 Upper	10/14/75 Lower
	%					
CH_4	55.1	51.5	--*	45.0	50.5	52.3
CO_2	41.5	39.0	--	34.7	39.9	39.3
O_2	0.7	2.1	20.8	4.2	2.0	1.8
N_2	2.7	7.4	79.2	16.1	7.5	6.6

*Below detection limit

The Phase II analytical results were also within the concentration ranges for natural waters. Except for iron, nickel, zinc, and possibly lead, the contaminant concentrations were quite close in both phases. Soluble iron and zinc in the background samples were as high as 2.3 and 3.8 ppm, respectively. Background nickel and lead concentrations were higher in Phase II than in Phase I, probably because of variations in sampling location and season.

The Phase II background groundwater contaminant concentrations varied seasonally, higher in the summer than in the winter. U.S. Weather Bureau statistics (5) indicate that Site 1 generally receives more rain in summer than in the winter, and the control volume analyses, to be presented later, show higher rates of groundwater flow in the summer. The higher contaminant levels in the summer may result, since the higher flow rates can transport fine particulates in the groundwater. The fine particulates probably comprise part of the concentration levels determined by analysis in this study. The data show that dilution effects may not be significant during the summer.

Phase II results indicated that samples from deeper locations in the background well usually had higher contaminant concentrations, the highest concentrations usually occurring in the sand-gravel (aquifer) layer. The sand-gravel stratum appeared to allow larger contaminant transport than comparable sandy clay soil. This phenomenon can be explained by the following:

- Clay has a higher surface sorption capability than sand, so that attenuation of contaminants by clay is more significant than by sand.

- Clay is generally less permeable than sand, so the flux rate is less and provides more time for various reactions to occur.

Off-Site Well Groundwater--

Data from the off-site shallow well (OS-X) showed that the concentrations of contaminants again varied with time. Concentrations of TOC varied between 8 and 52 ppm; however, there did not seem to be any significant correlation between concentration and season for the TOC changes. Nitrogen compound results were available for only two sampling times for the OS-X well. The concentrations for TKN and ammonium-nitrogen were about 1 to 3 ppm and 0.15 to 1.3 ppm, respectively. Nitrate was in relatively low levels ranging from a trace to 0.25 ppm. Chloride and sulfate concentrations ranged from 25 to 70 ppm and 238 to 430 ppm, respectively. No seemingly significant relations in the concentration trends were found among the contaminants; with the exception of iron and zinc, all the concentrations of trace heavy metals in the OS-X well samples analyzed had less than 0.1 ppm, the majority less than 0.01 ppm. The concentration of iron increased from 0.33 to 8.3 ppm, zinc from about 0.01 to 3 ppm.

The analytical data fo wells OS-1 to OS-6 in the Phase II monitoring are given in Table 1 of Appendix E. In general, the concentrations of contaminants in samples from wells OS-1 to OS-6 were within the ranges of the concentrations of the OS-X samples. Concentration trends of various selected contaminants in relation to sampling time and depth are discussed below.

Chloride--Chloride concentrations in the groundwater from wells OS-1 and OS-6 ranged from <2 to 65 ppm. Concentration versus time curves showed that, in general, chloride gradually decreased during the Phase II monitoring (Figure 20). Since chloride is relatively non-reactive and anion exchange capacity of soils is generally low, it appears that the concentration change observed was mainly caused by a decrease in the upstream source.

When chloride concentrations from different sampling levels of the same well were compared, groundwater samples from lower depths usually contained higher chloride concentrations. This was probably due to the migration of chloride into the deep groundwater.

Sulfate--Concentrations of sulfate in the OS well groundwater decreased or fluctuated during the Phase II monitoring (Figure 21). The fluctuations may be due to the reduction and oxidation of the sulfide solids (see Special Control Volume Analyses). In addition, the sulfate data also showed higher concentrations and transport flux in the sand formation than in the clay formation.

TOC--A large decrease in TOC was observed during the year-long monitoring (Figure 22). However, unlike chloride or sulfate, TOC concentrations generally decreased with sampling depth. Since March 1977, TOC concentrations in the downstream groundwater appeared relatively constant, with values hovering around 5 ppm. This could be due to disappearance of drilling muds. As will be discussed in the Special Control Volume Analyses, TOC could be strongly attenuated by soil which could account for the observed decrease in TOC concentrations.

Trace Metals--Concentrations of cadmium, chromium, copper, and nickel were near or below the equipment detection limits in this study. Therefore, it was difficult to identify the migration trends of these elements in the groundwater. Iron, lead, zinc, and mercury concentrations were higher than detection limits; changes in concentration with sampling time for these four metals are shown in Figures 23 to 26.

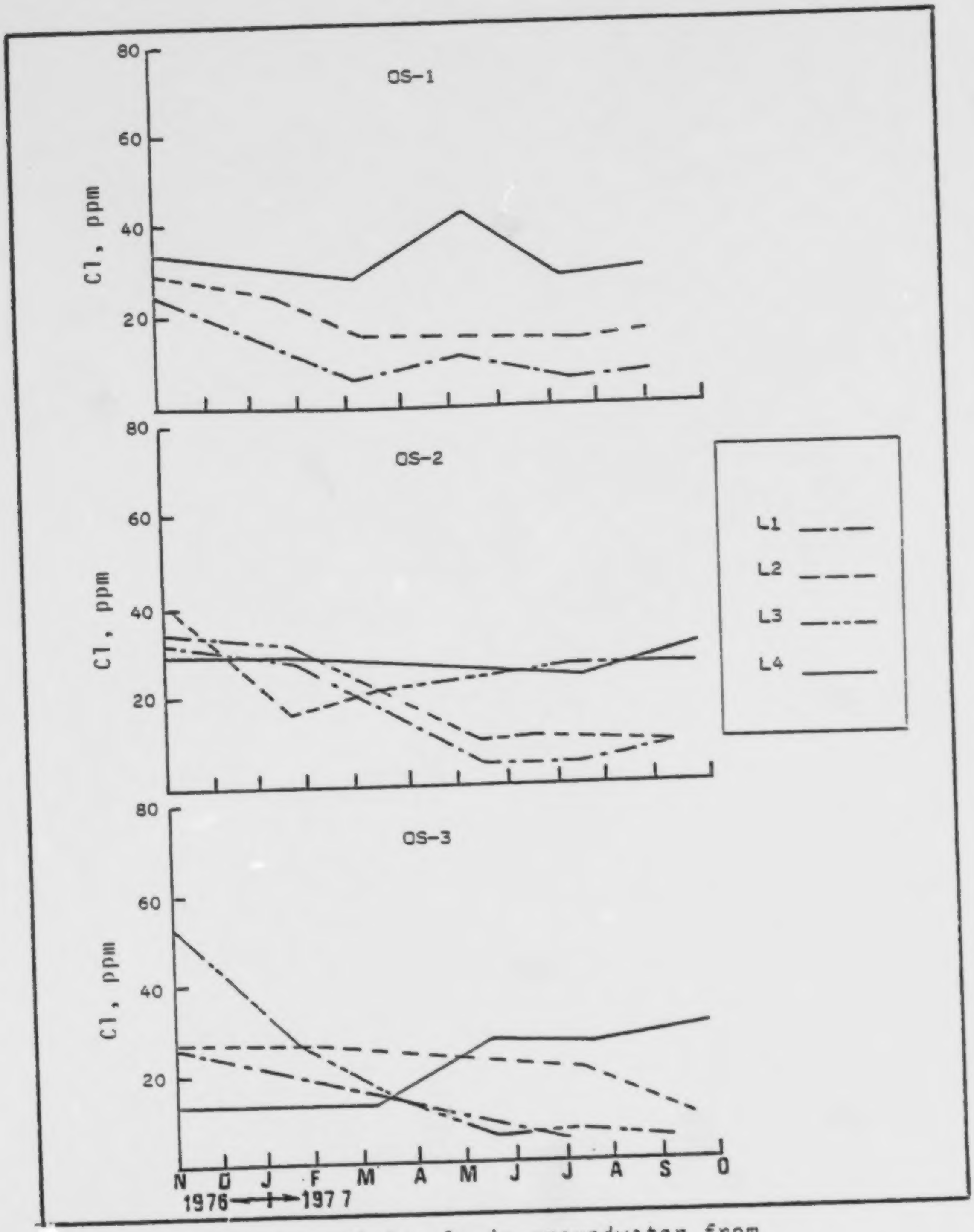


Figure 20. Cl levels in groundwater from six off-site wells (site 1).

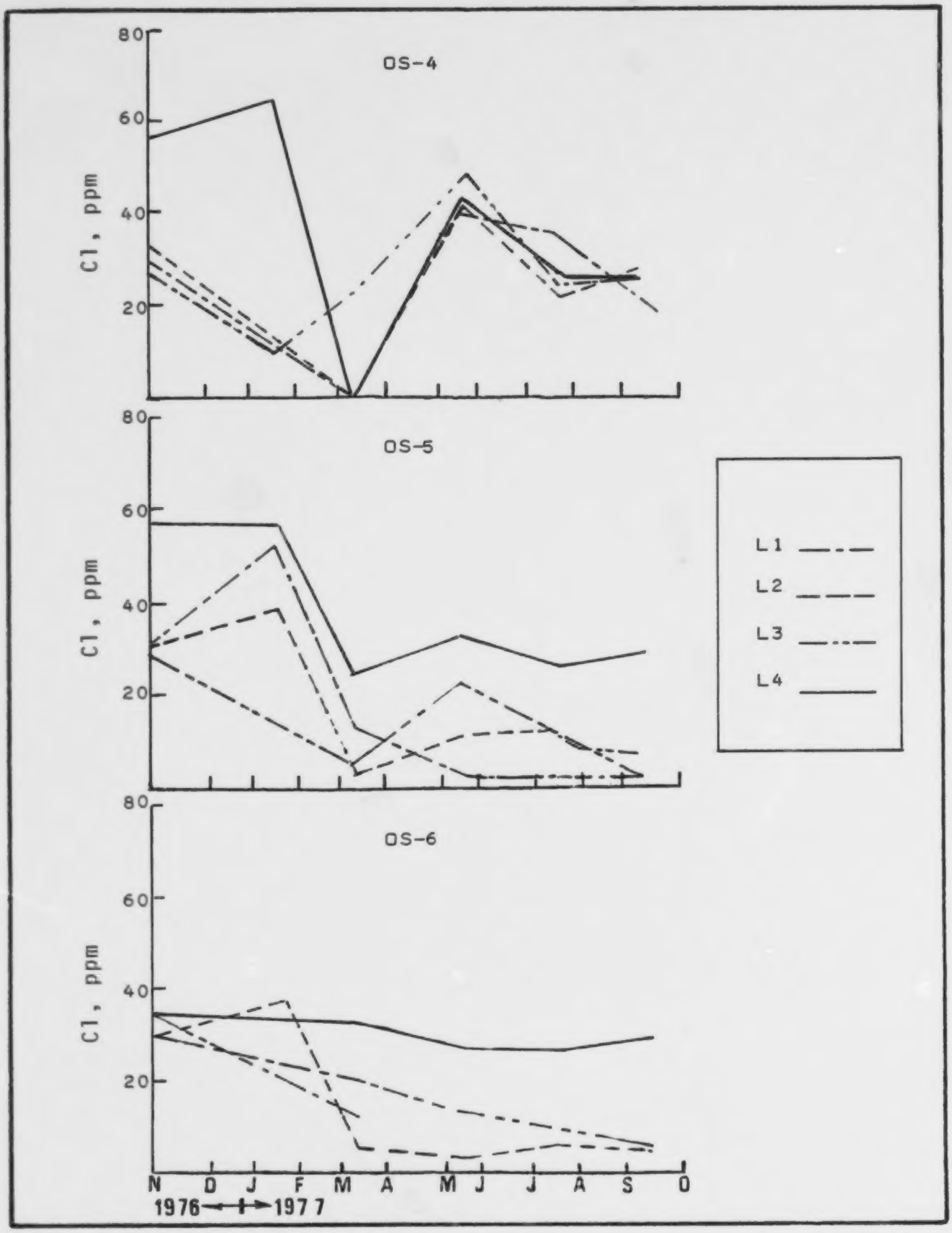


Figure 20 (Continued)

(99)

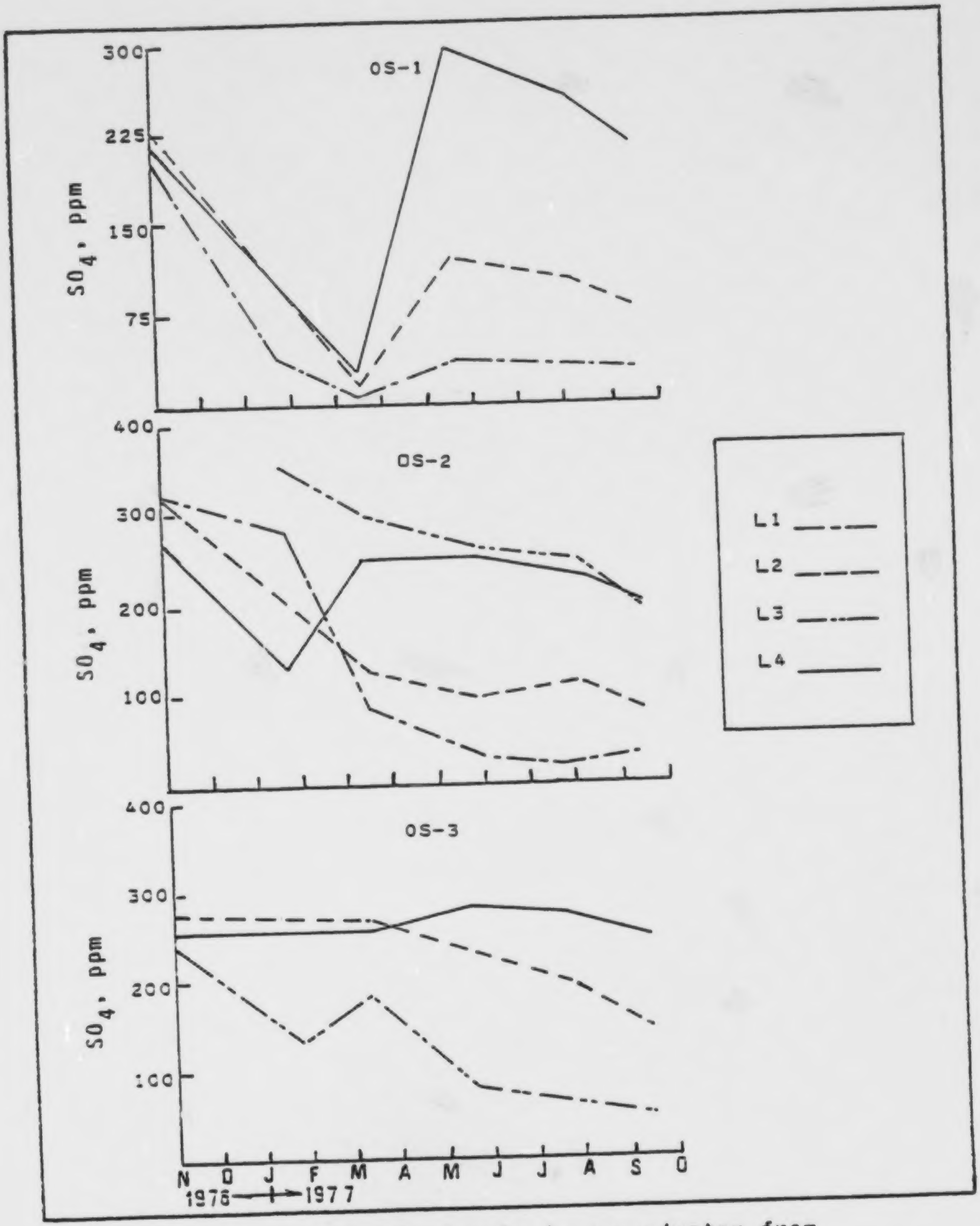


Figure 21. SO_4 levels in groundwater from six off-site wells (site 1).

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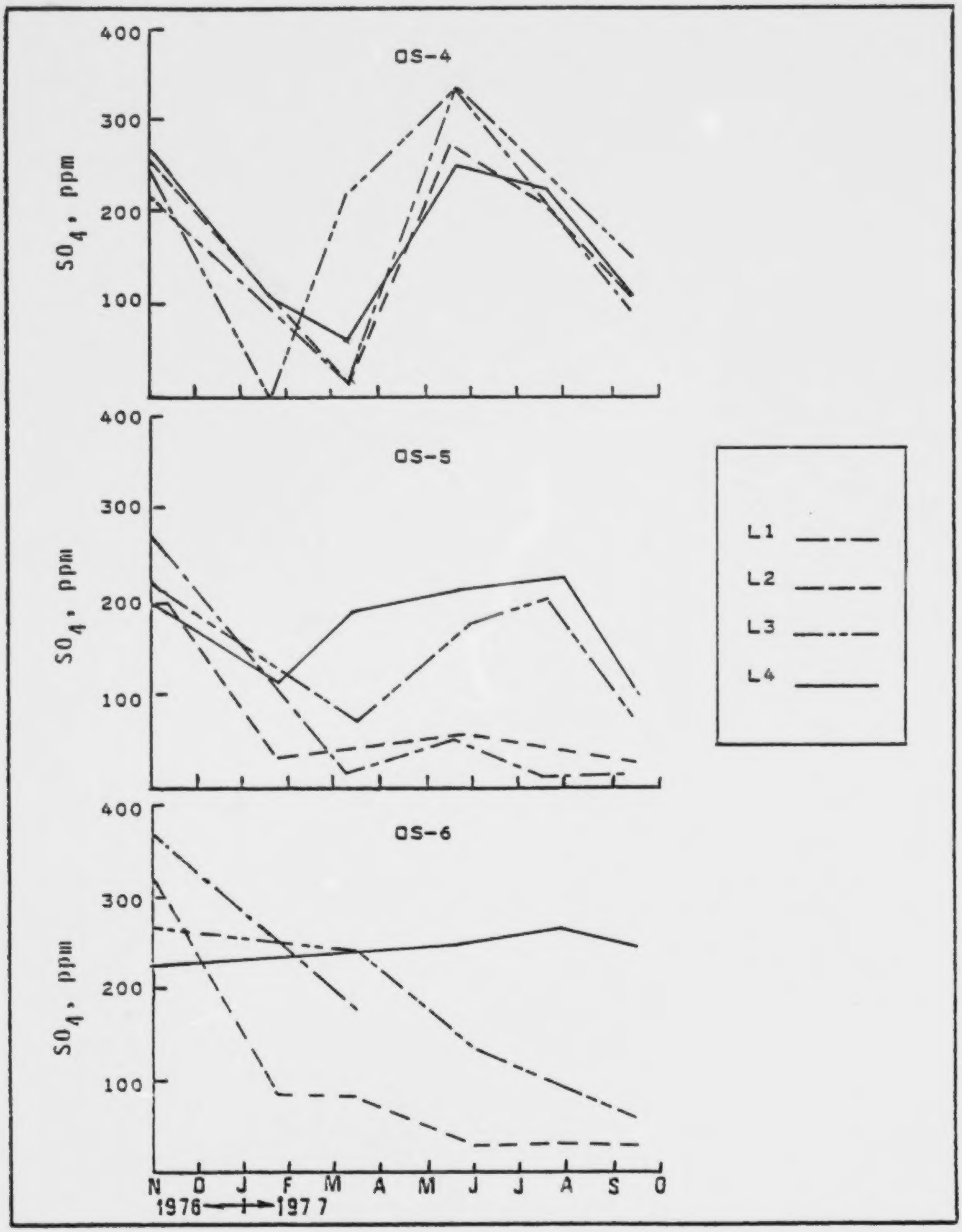

Figure 21 (Continued)

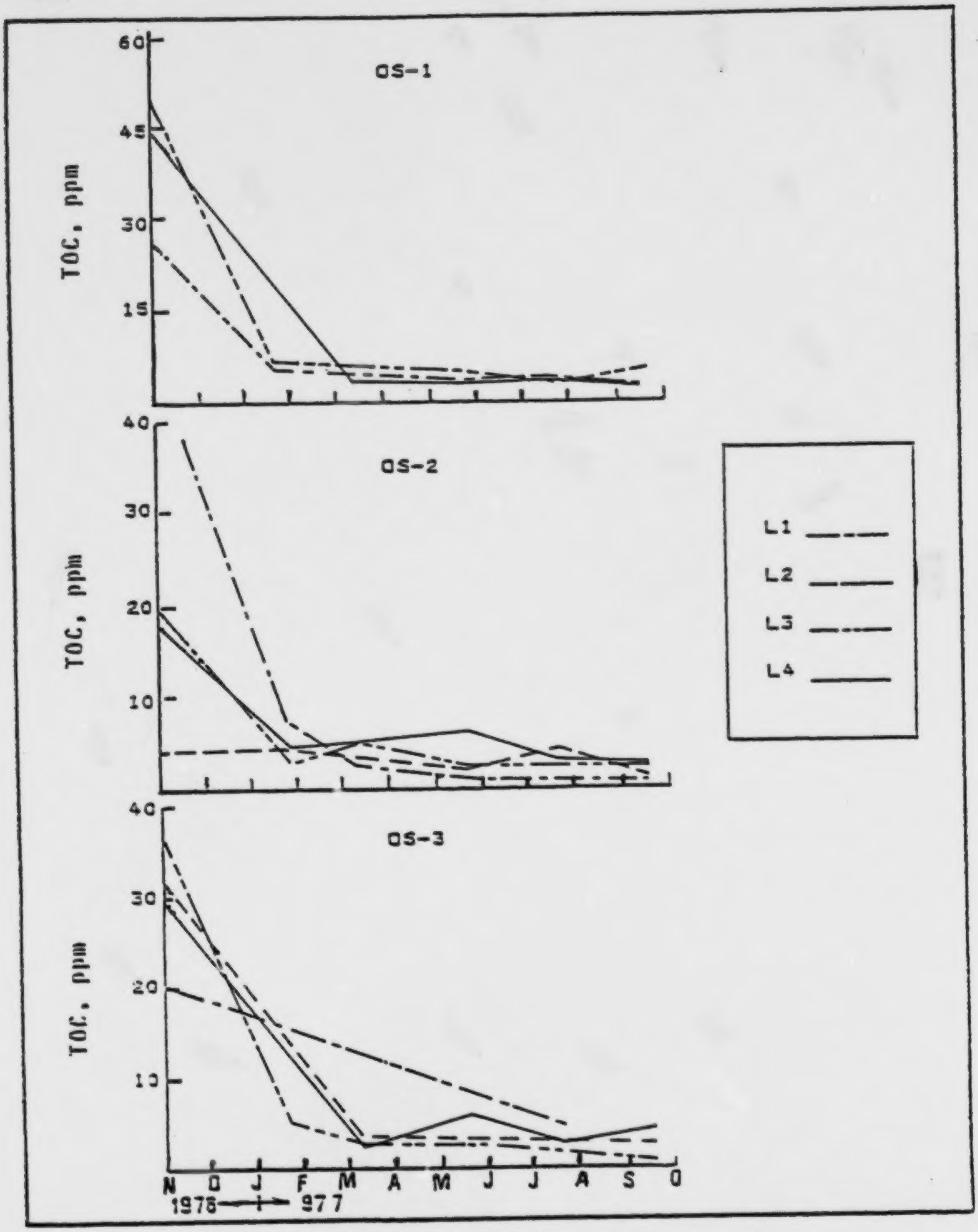

Figure 22. TOC levels in groundwater from six off-site wells (site 1).

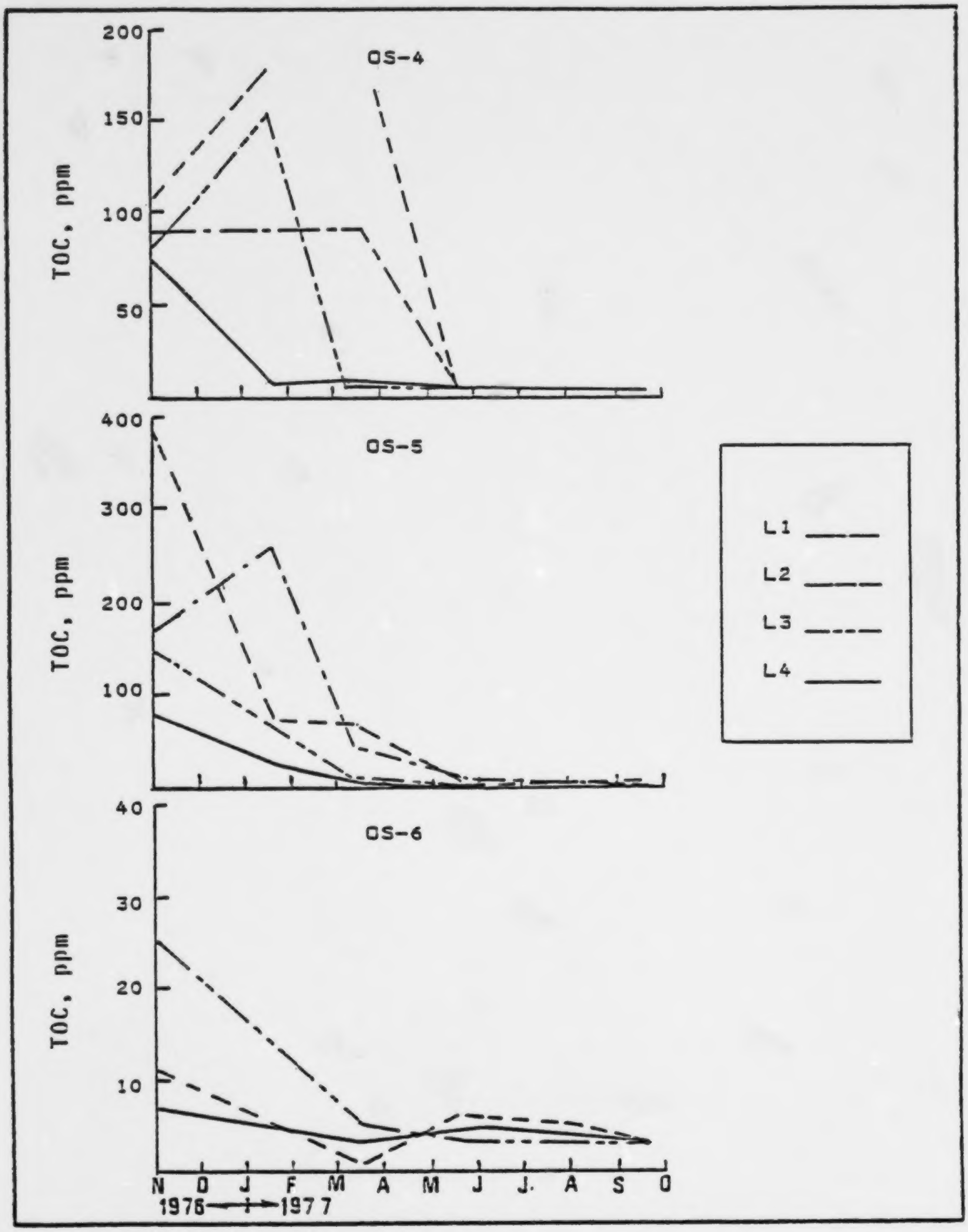

Figure 22(Continued)

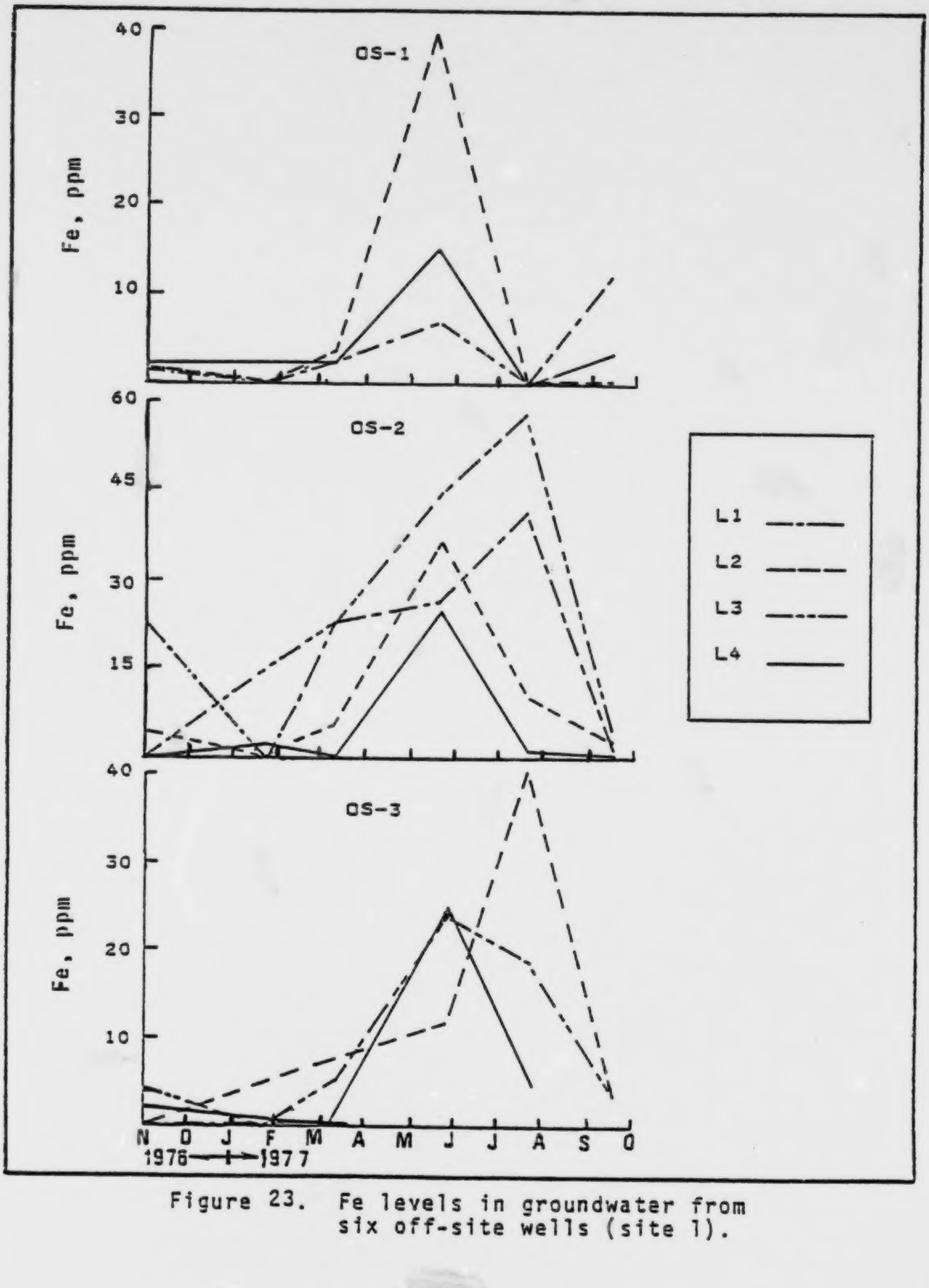

Figure 23. Fe levels in groundwater from six off-site wells (site 1).

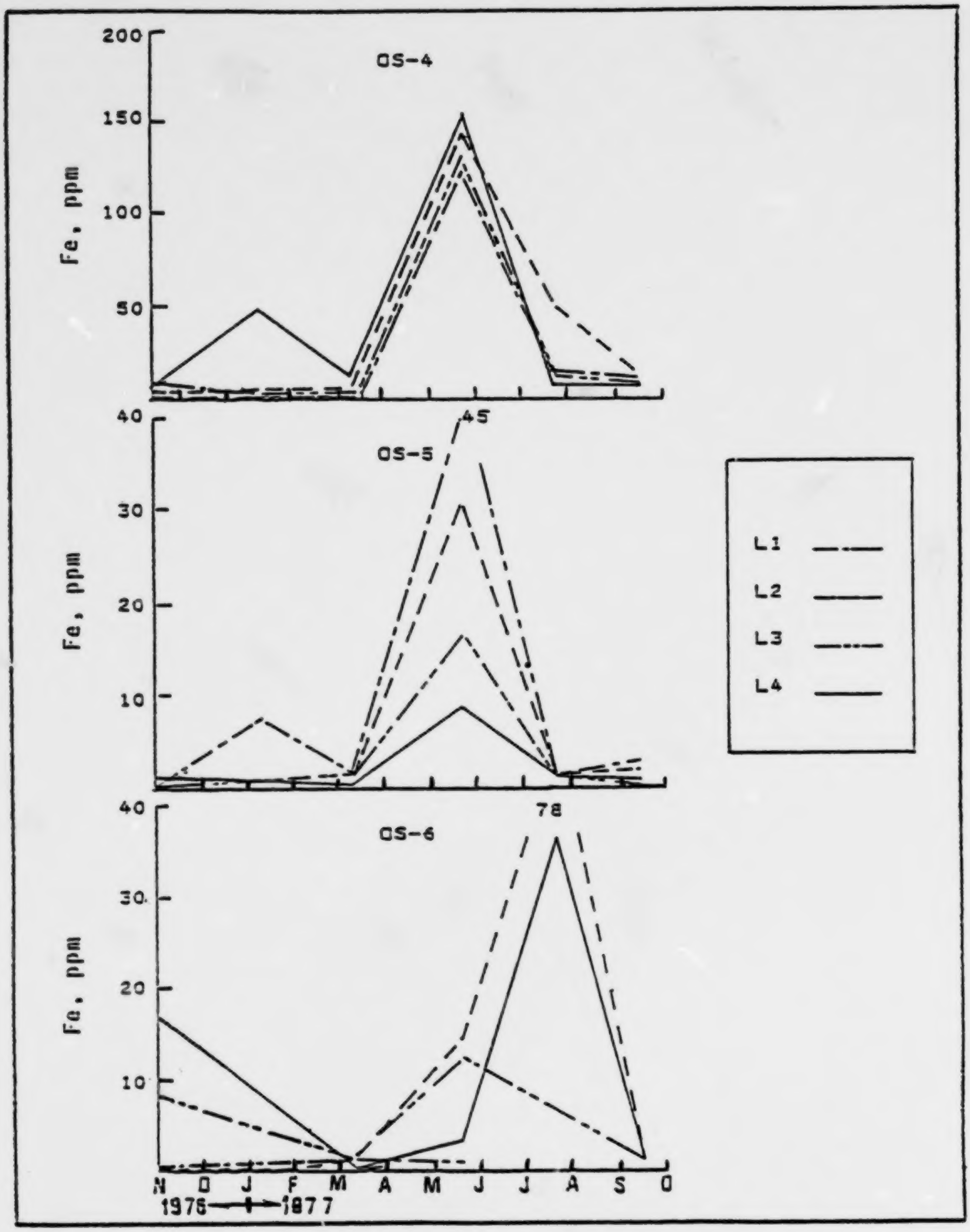

Figure 23 (Continued)

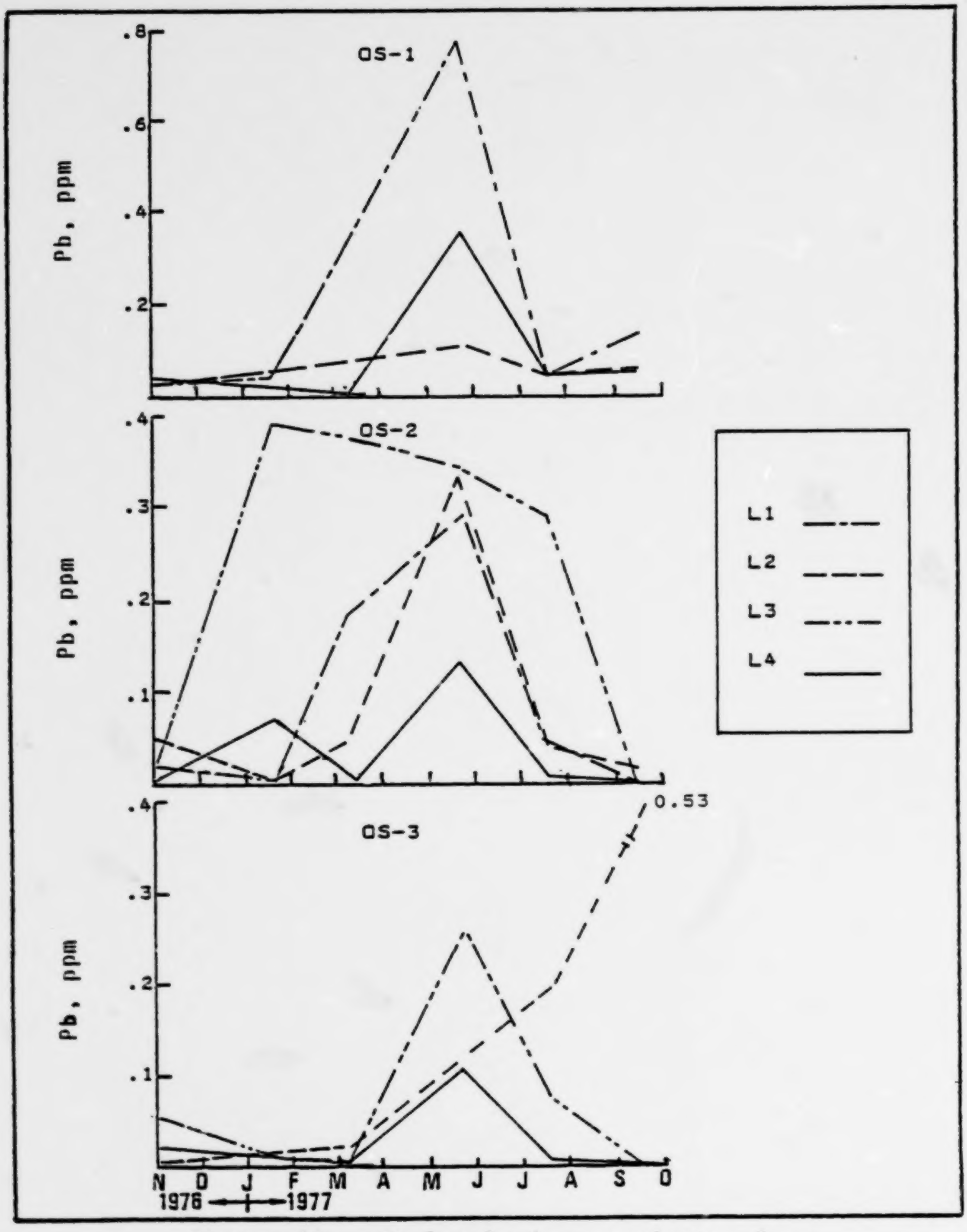

Figure 24 . Pb levels in groundwater from six off-site wells (site 1).

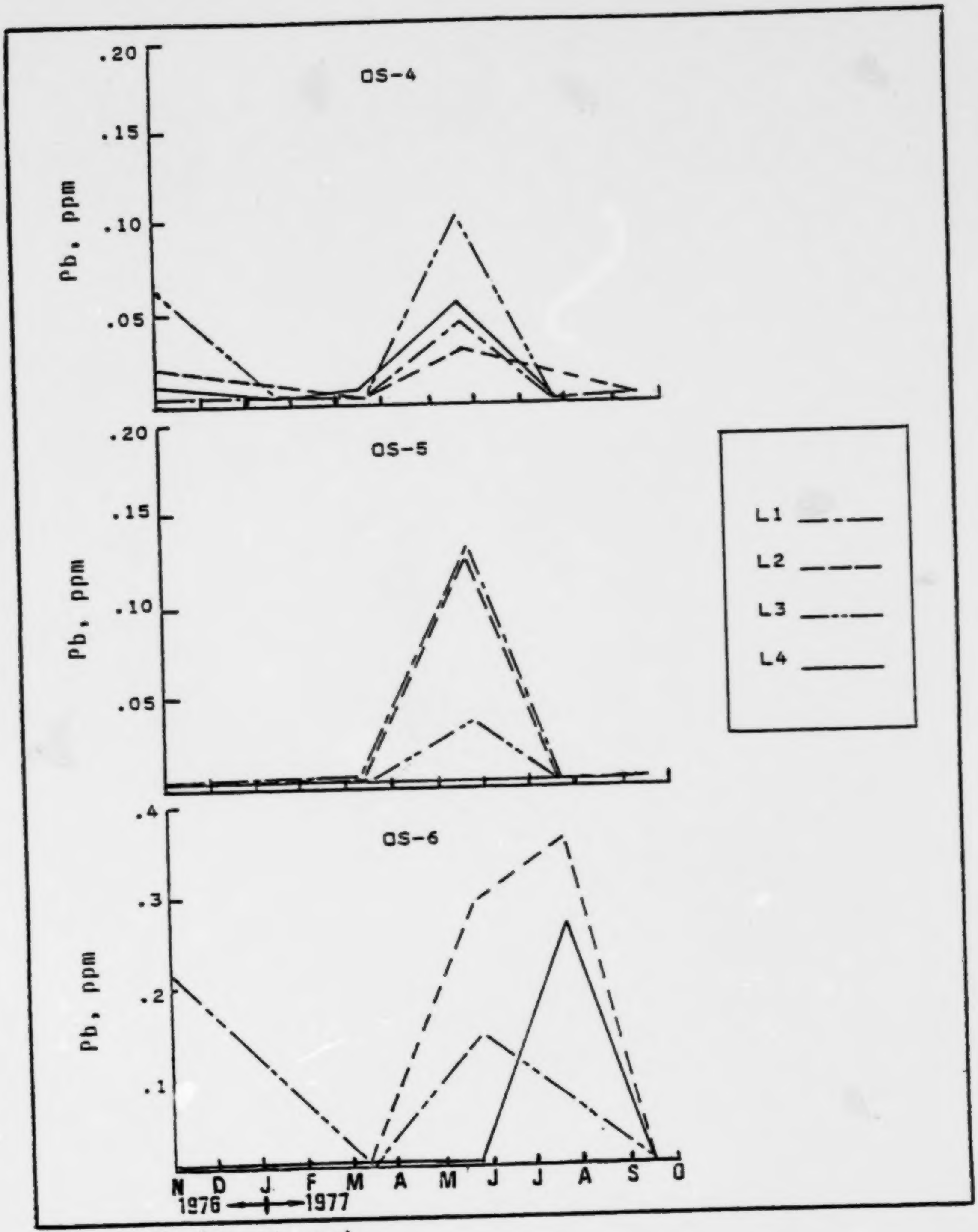

Figure 24 (Continued)

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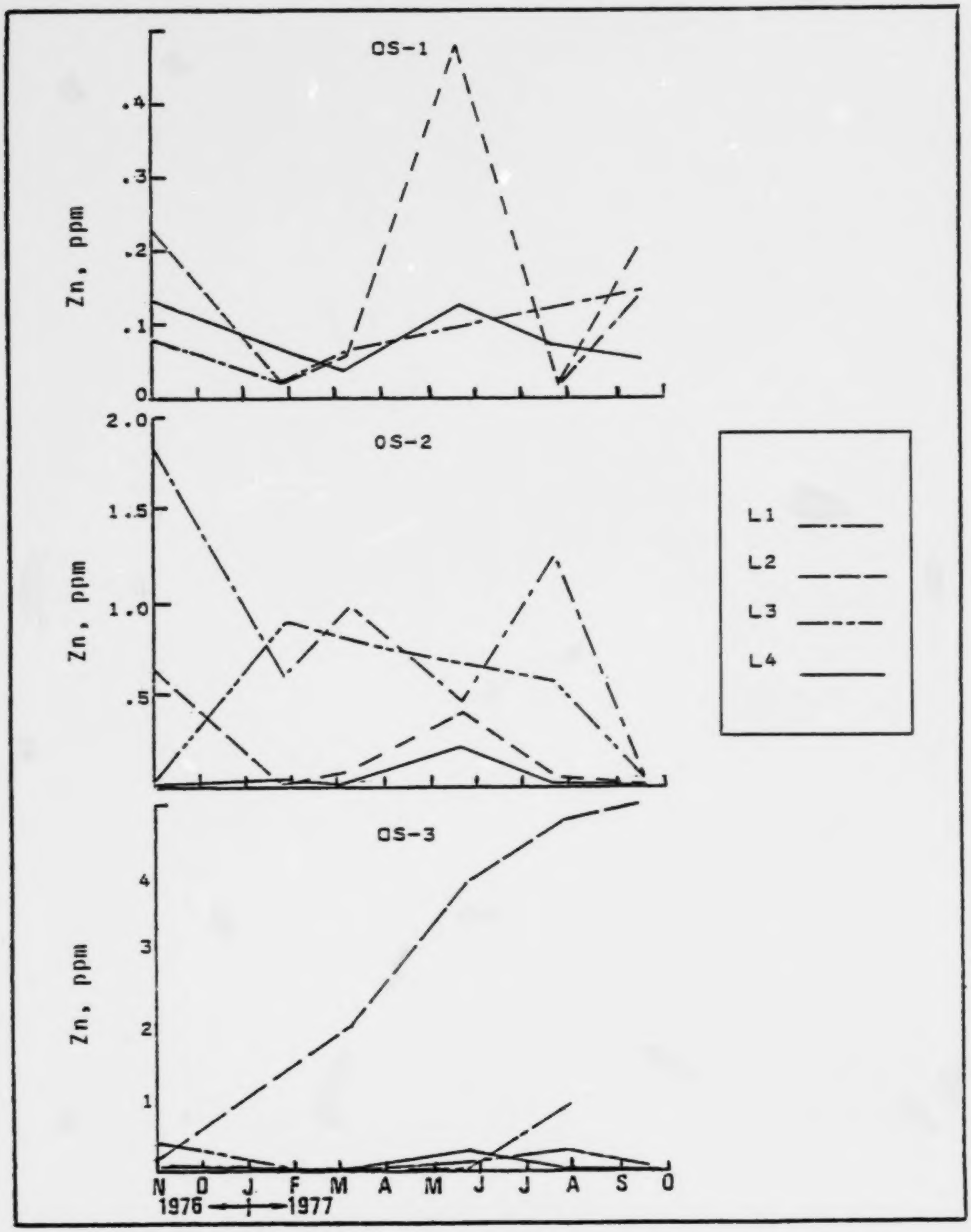

Figure 25. Zn levels in groundwater from six off-site wells (site 1).

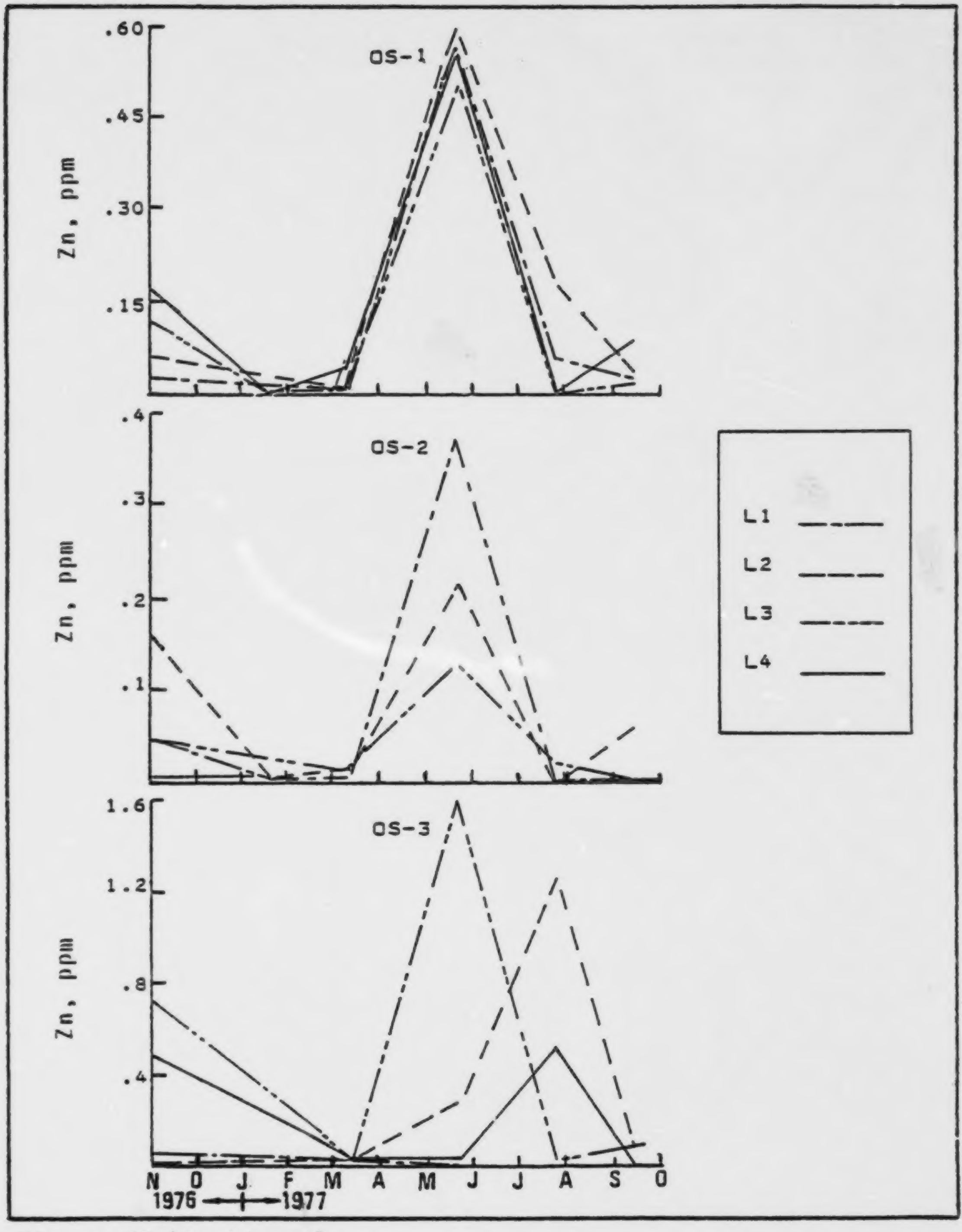

Figure 25 (Continued)

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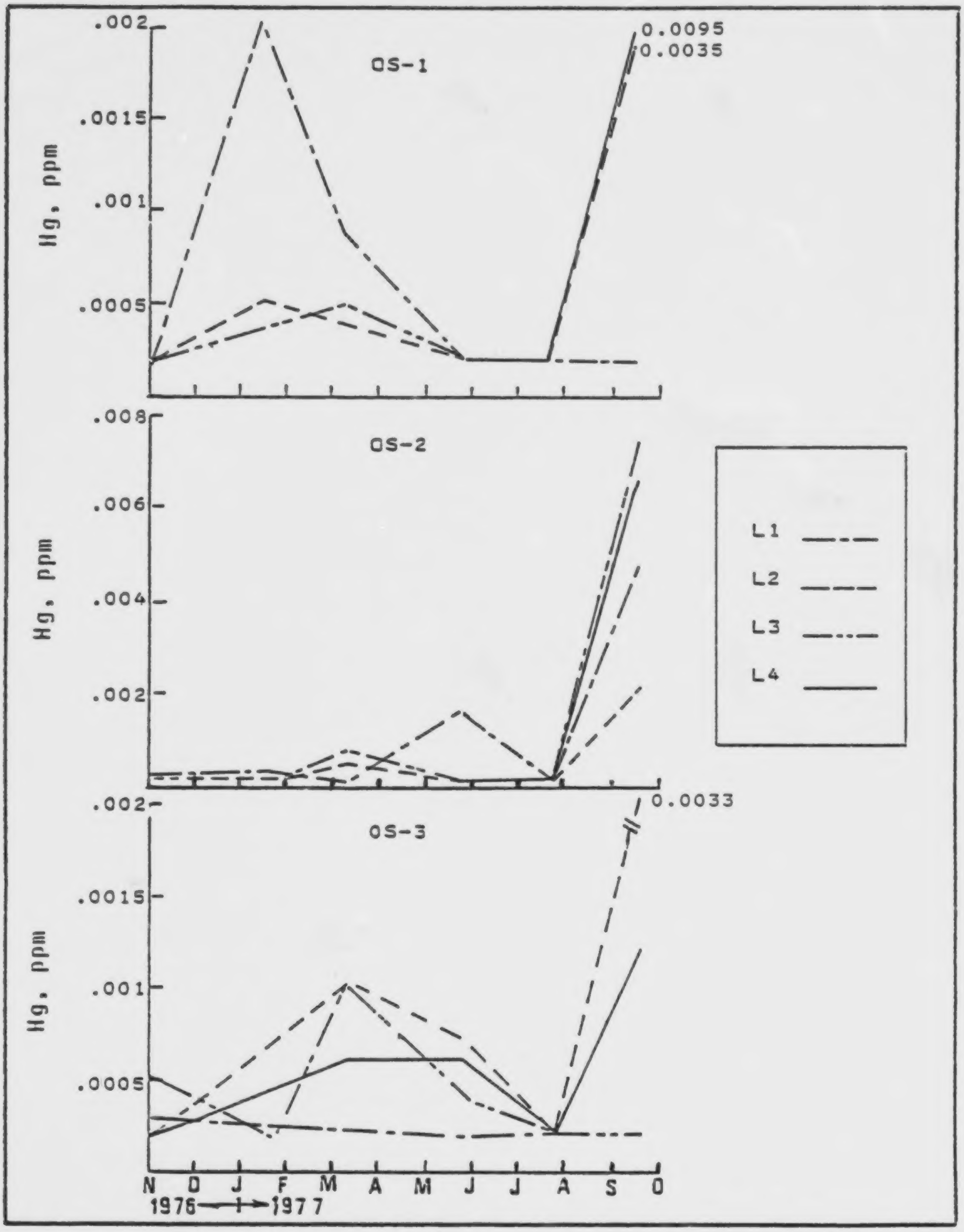

Figure 26. Hg levels in groundwater from six off-site wells (site 1).

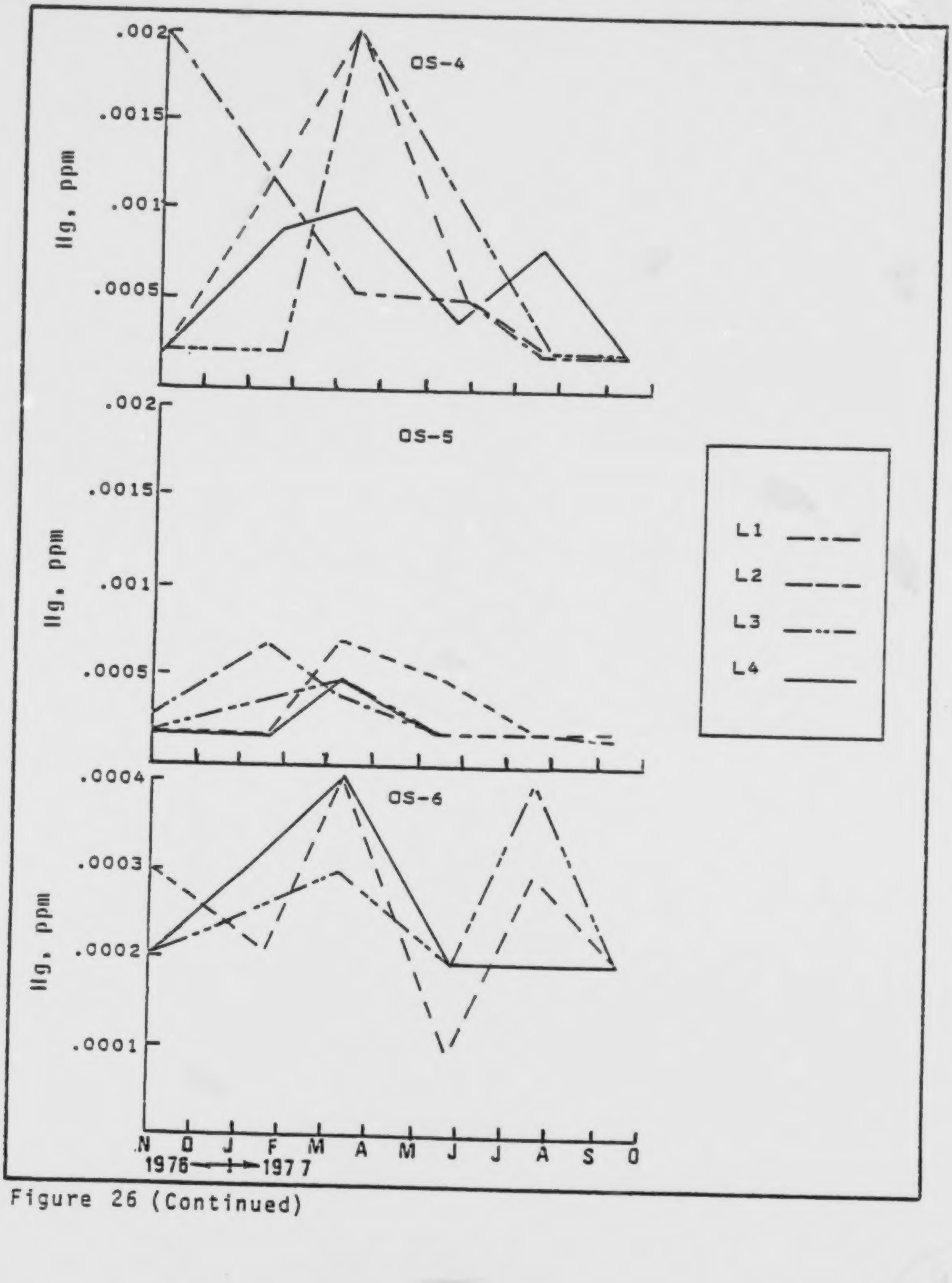

Figure 26 (Continued)

Iron concentrations in the downstream groundwater ranged from <0.01 to 152 ppm. The highest concentrations of iron occurred in the OS wells during the summer. Reducing conditions or iron-organic complex formation are generally the main reasons for the increase of soluble iron in natural water (7, 8). However, because of the high precipitation (infiltration) and groundwater flow rate, the redox condition of the downstream groundwater should be higher in the summer. The relatively higher redox condition and higher dilution ratio, coupled with the lower TOC levels in the summer, could remove more soluble iron from the liquid phase. Therefore, the increase in iron concentration in the summer season at this site is likely due to the high flow rate that leached more fine particles into the groundwater.

Time variations of mercury in the off-site groundwater were irregular (Figure 26). However, in many cases, mercury concentrations were below the detection limit, and no higher concentration than 10 ppb was observed. In the downstream wells, only 7 out of 124 sampled concentrations exceeded 2 ppb for the entire monitoring period.

Unlike chloride or sulfate, trace metals showed no apparent correlation between concentration and sampling level. As suggested by Lu (7), in regulating the migration of trace metals in the environment, the conditions of the solution phase are usually far more important than those of the solid phase. This is probably why the migration of trace metals was not apparently affected by the characteristics of the geologic formation in the aquifer.

Comparisons Among In-Refuse Well Background and Downstream Groundwaters--

In the Phase I study, all contaminants studied showed either the same or lower concentrations in the background groundwater than in the downstream groundwater; only one data point for zinc showed a higher level in the background than in the downstream groundwater.

In the Phase I study, TOC and iron levels were substantially higher in the in-refuse well leachate than in the downstream groundwater, while sulfate was the only contaminant with substantially lower levels in the in-refuse well leachate. Levels of other trace metals in the leachates did not differ significantly from those in the downstream groundwater.

Since different sampling levels were involved in the Phase II study, it was very difficult in some cases to evaluate the relative concentrations because of time and depth variations. Average values will be used in the comparison. Average concentrations of contaminants in the in-refuse, background, and off-site well (downstream) groundwaters are given in Figures 27 to 29. These concentrations were much higher in the in-refuse leachates than those in background or downstream groundwater, except for sulfate and mercury. The low levels of mercury were probably caused by the low solubility of the mercury sulfide solid and the high affinity of mercury to the sludge particles. The low levels of sulfate were probably caused by the high reducing environment and the concomitant high organic content of the sludge. These phenomena are consistent with the results of the Phase I study.

Concentrations of sulfate, TOC, and zinc were significantly higher in downstream groundwater than in background groundwater, while other contaminants showed no definite trends. This implies that the quality of the original groundwater, the types of soil, and the characteristics of landfill material play important roles in determining the migration of contaminants.

Special Control Volume Analyses

Flow Calculations--

As previously discussed (Section 5), the direction and magnitude of groundwater flow can be calculated from permeability (K_K), hydraulic gradients (S_x, S_y, and S_z), and porosity (n_K). From the numerous boring tests, it was determined that the special control volume of Site 1 included three types of soil layers: silty fine sand, sandy clay, and sand-gravel. The permeabilities of these soil layers were 4.73×10^{-3}, 3.53×10^{-4}, and 7.06×10^{-2} cm/sec, respectively (5). The porosity of the silty fine sand layer was 0.3, that of the sandy clay and sand-gravel (aquifer) layers, 0.5. The hydraulic gradient changed from time to time as shown by the piezometric groundwater elevations of EX wells (Appendix B). As explained in Section 5, values of S_x, S_y, and S_z at different time periods can be calculated by using the EX wells' piezometric groundwater elevation data. Since groundwater elevation data for well EX-3 are incomplete, the data of October 31, 1976, was substituted for the other dates when calculating S_x and S_y and the related V_x and V_y values (Tables 12 and 13).

The geological consultant indicated that in a normal situation the vertical flow, V_z, might not exist below the regional groundwater table, especially in the sand-gravel (aquifer) layer. V_z would become important only when local pumping of the groundwater or precipitation occurred, and it existed only beneath the landfill site. However, due to the relatively large horizontal regional water flow, even during the precipitation or pumping, V_z probably occurred chiefly in the shallow zone below the groundwater table. Since V_z could not be accurately calculated, it was assumed to be zero for the purposes of these calculations. Although this assumption may introduce some error into the flow and transport model results,

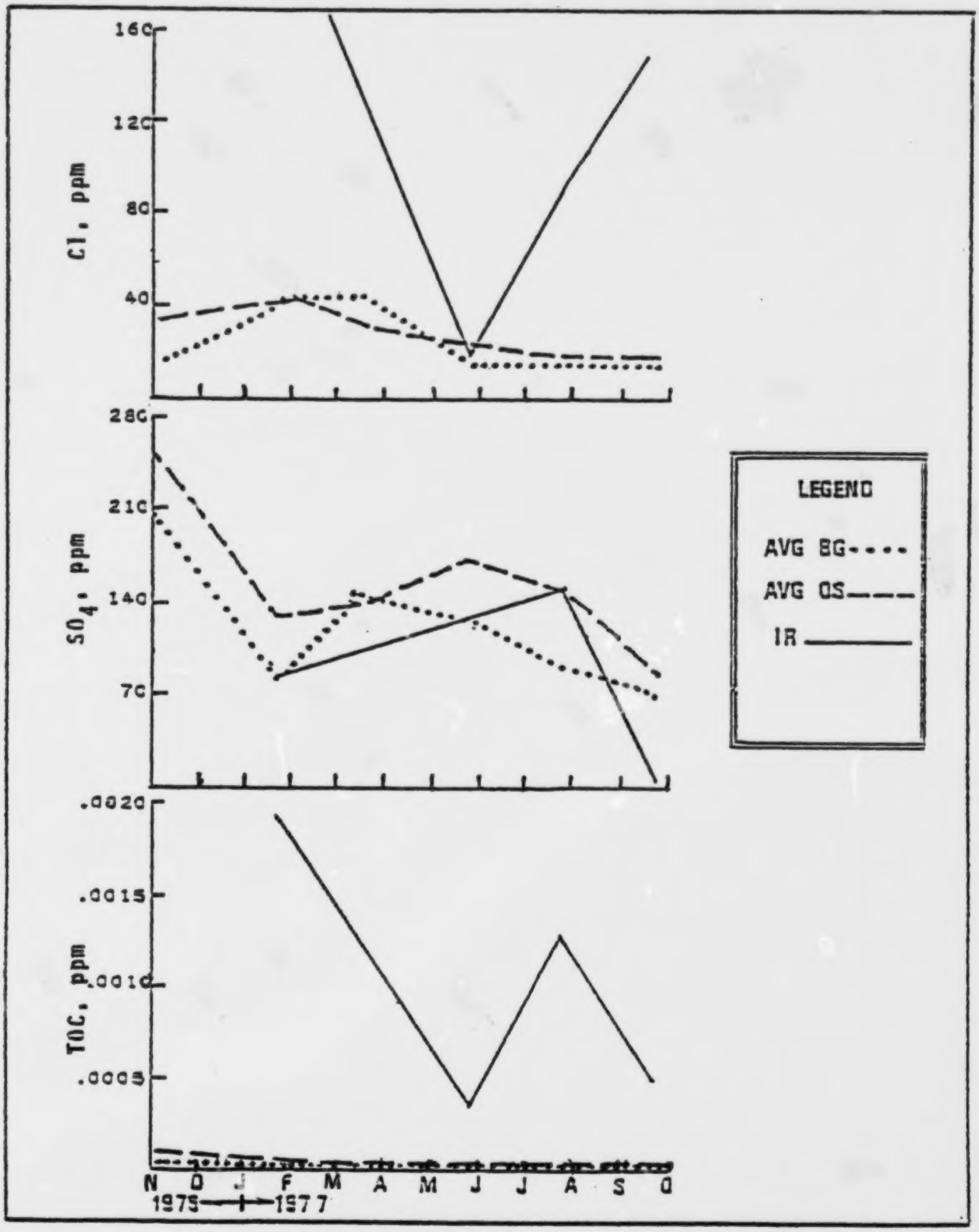

Figure 27. Cl, SO_4, and TOC levels in groundwater and leachate (site 1).

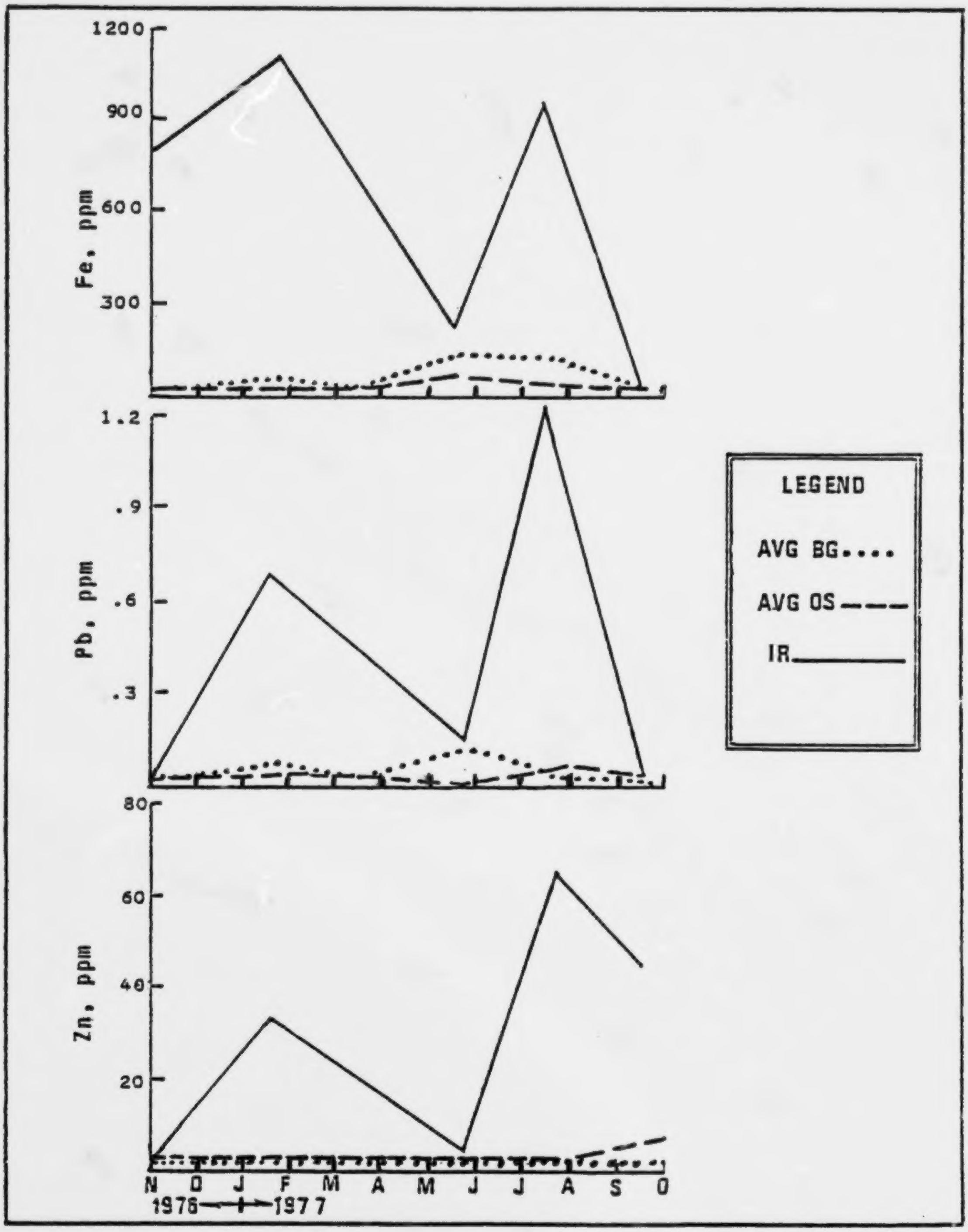

Figure 28. Fe, Pb, and Zn levels in groundwater and leachate (site 1).

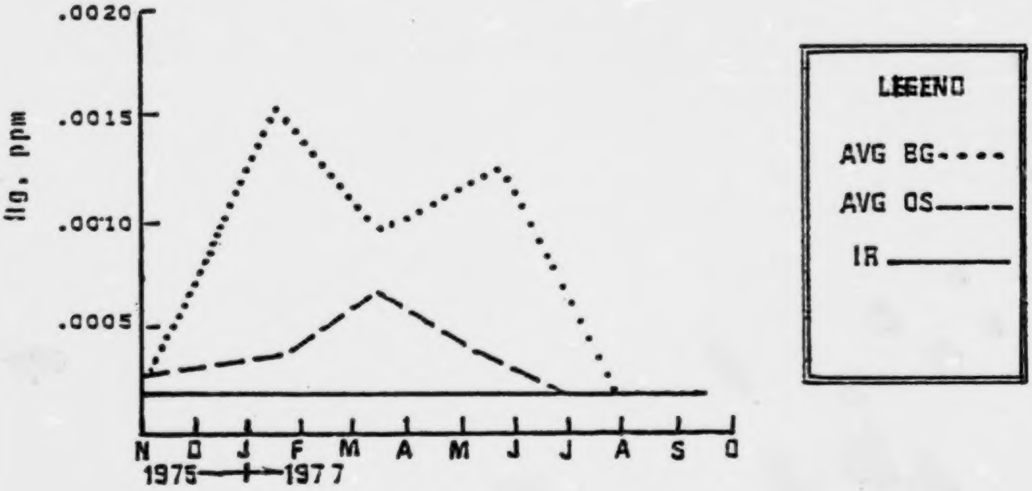

Figure 29. Hg levels in groundwater and leachate (site 1).

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TABLE 12. SITE 1 CONTROL AREAS, HYDRAULIC GRADIENTS, AND FLOW VELOCITIES IN X-DIRECTION

Inlet Section		Outlet Section						
Area Symbol*	Area (m^2)	Area Symbol*	Area (m^2)	Type of Soil†	K (cm/sec)	n	S_x #	V_x (cm/day)
A431	70.0	A111	68.0	C	3.47×10^{-4}	0.5	0.004	0.24
A441	23.2	A211	168.0	C	3.47×10^{-4}	0.5	0.004	0.24
A511	116.0	A321	136.0	C	3.47×10^{-4}	0.5	0.004	0.24
A521	70.0	-	-	C	3.47×10^{-4}	0.5	0.004	0.24
A621	93.0	-	-	C	3.47×10^{-4}	0.5	0.004	0.24
A442	256.0	A112	80.3	A	7.06×10^{-2}	0.3	0.004	81.0
A522	151.0	A122	106.0	A	7.06×10^{-2}	0.3	0.004	81.0
A532	209.0	A212	84.0	A	7.06×10^{-2}	0.3	0.004	81.0
A542	151.0	A222	210.0	A	7.06×10^{-2}	0.3	0.004	81.0
A622	5.8	A232	168.0	A	7.06×10^{-2}	0.3	0.004	81.0
A632	128.0	A332	170.0	A	7.06×10^{-2}	0.3	0.004	81.0
A642	122.0	A342	204.0	A	7.06×10^{-2}	0.3	0.004	81.0

*Aijk, where i = offsite well number; j = level of sampling point; k= soil layer; 1 = sandy clay; and 2 = sand gravel (aquifer layer).

†C = sandy layer and A = aquifer.

#Assume S_x is kept constant for the entire experimental period.

TABLE 13. SITE 1 HYDRAULIC GRADIENTS AND FLOW VELOCITIES IN Y-DIRECTION

Type of Soil*	Period	K (cm/sec)	n	Sy†	Vy† (cm/day)
C	10/31/76 → 12/11/76	3.47×10^{-4}	0.5	0.001	0.06
A	(41 days)	7.06×10^{-2}	0.3	0.001	20.4
C	12/11/76 → 1/21/77 → 2/14/77	3.47×10^{-4}	0.5	0.0006	0.037
A	(65 days)	7.06×10^{-2}	0.3	0.0006	12.2
C	2/14/77 → 3/10/77 → 4/14/77	3.47×10^{-4}	0.5	0	0
A	(59 days)	7.06×10^{-2}	0.3	0	0
C	4/14/77 → 5/19/77 → 6/19/77	3.47×10^{-4}	0.5	0.0008	0.049
A	(66 days)	7.06×10^{-2}	0.3	0.0008	16.2
C	6/19/77 → 7/19/77 → 8/17/77	3.47×10^{-4}	0.5	-0.0008	-0.049
A	(59 days)	7.06×10^{-2}	0.3	-0.0008	-16.2
C	8/17/77 → 9/14/77	3.47×10^{-4}	0.5	0.0046	0.28
A	(28 days)	7.06×10^{-2}	0.3	0.0046	93.6

* C = sandy layer and A = sand-gravel (aquifer).

† Positive value means the flow direction was from OS-4 toward OS-6 (see Figure 30).

they may not be significant for the control volume in the aquifer layer.

Flow directions and magnitudes were calculated from the results of V_x and V_y (Figure 30 and Table 14). These results showed that the directions of flow in the aquifer layer deviated from the presumed longitudinal axis of the downstream leachate plume by an angle of 0^o to 49^o. The horizontal velocities ranged from 62 to 124 cm/day in this layer. The directions of flow in the sandy clay layer above the aquifer also deviated in the same range, but flow velocities were as low as 0.24 to 0.37 cm/day in this layer.

Control Area A_{ijk} and Flow Rate--

The control volume was reoriented and new boundaries defined following the methods suggested in Section 5. The plane orientation (top view) of this revised control volume is shown in Figure 30. The inlet plane is unchanged (OS-4 to OS-6 constant), while the outlet plane is changed according to angle θ. The surface area of partitioned subareas A_{ijk} on the inlet and outlet planes was calculated between the 548.6 to 557.8 m elevations (Figures 31 and 32), and the results given in Tables 15 and 16. The amount of flow crossing each subarea, A_{ijk}, was calculated as the product of A_{ijk} times the appropriate velocity, $V_{H,K}$. These results are also listed in Tables 15 and 16.

Mass Balance--

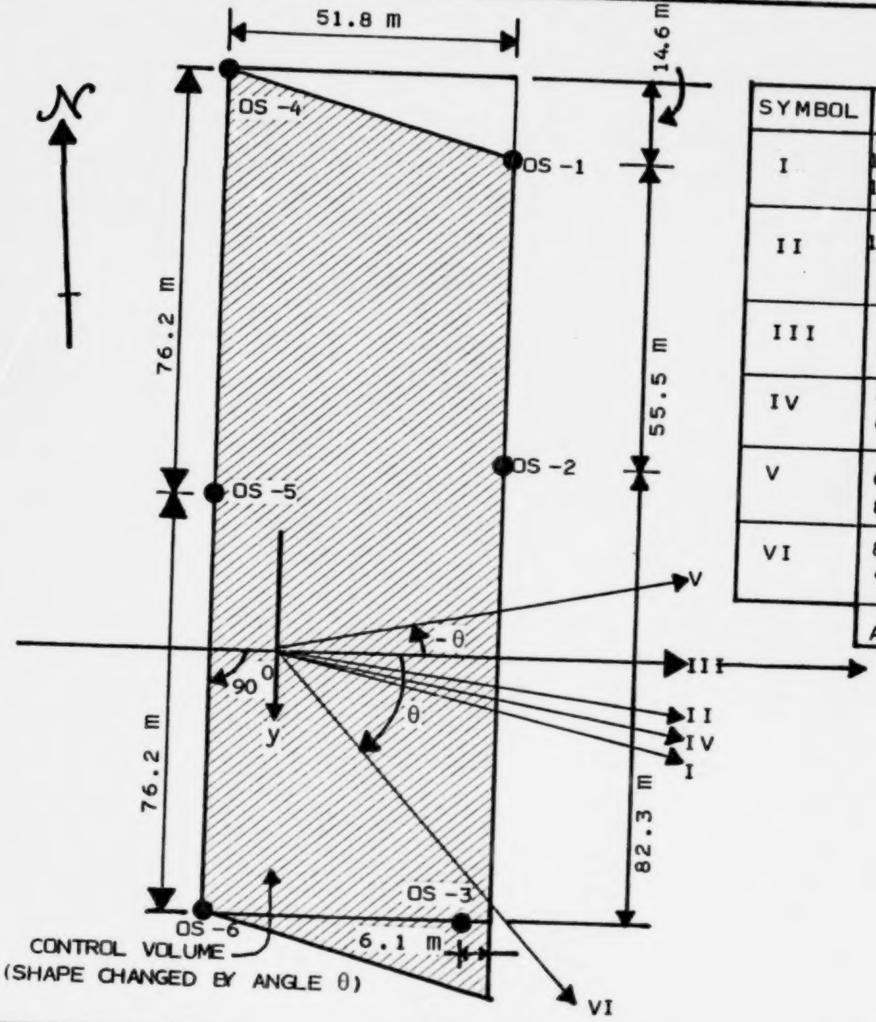
Input and output contaminant fluxes, J (kg/day), through the inlet and outlet boundaries can be solved by Equation 43, which, by converting the units, is equal to

$$J \text{ (kg/day)} = C \text{ (ppm} \times \theta \text{ (m}^3\text{/day)} \times 10^{-3} \qquad (46)$$

Results of J are given in Tables 15 and 16. These results can be converted to unit flux by dividing average J values by the input or outlet areas. The unit input and output fluxes and their differences are given below:

Contaminant	Unit Input Flux	Unit Output Flux	Difference
Cl^-	25.9	14.7	11.20
SO_4^{2-}	133	141	-8.00
TOC	39.6	3.66	35.9
Fe	15.2	12.6	2.6
Hg	0.00046	0.00046	0
Pb	0.024	0.134	-0.11
Zn	0.093	0.27	-0.18

(Units are in $g/d/m^2$)


51.8 m
14.6 m
N
OS -4
OS -1
76.2 m
55.5 m
OS -5
OS -2
V
-θ
III
0
90
y
θ
II
IV
I
76.2 m
82.3 m
OS -3
OS -6
CONTROL VOLUME
(SHAPE CHANGED BY ANGLE θ)
6.1 m
VI

SYMBOL	PERIOD	θ	V_H(m/d)
I	10/31/76→ 12/11/76	14.1^0	0.84
II	12/11/76→ 2/14/77	8.5^0	0.82
III	2/14/77→ 4/14/77	0^0	0.81
IV	4/14/77→ 6/19/77	11.2^0	0.83
V	6/19/77→ 8/17/77	-11.2^0	0.83
VI	8/17/77→ 9/14/77	49^0	1.24
	AVERAGE	11.9^0	0.62

Figure 30. Directions of groundwater flow in aquifer layer of site 1.

TABLE 14. THE MAGNITUDE AND DIRECTION OF HORIZONTAL GROUNDWATER FLOW OF SITE 1.

Period	Type of Soil*	V_x (cm/day)	V_y† (cm/day)	θ†	V_H† (cm/day)
10/31/76 → 12/11/76	C	0.24	0.06	14.1°	0.25
(41 days)	A	81.0	20.4	14.1°	84.0
12/11/76 → 1/21/77 → 2/14/77	C	0.24	0.037	8.5°	0.25
(65 days)	A	81.0	12.2	8.5°	82.0
2/14/77 → 3/10/77 → 4/14/77	C	0.24	0	0°	0.20
(59 days)	A	81.0	0	0°	81.0
4/14/77 → 5/19/77 → 6/19/77	C	0.24	0.049	11.2°	0.25
(66 days)	A	81.0	16.2	11.2°	83.0
6/19/77 → 7/19/77 → 8/17/77	C	0.24	-0.049	-11.2°	-0.25
(59 days)	A	81.0	-16.2	-11.2°	-83.0
8/17/77 → 9/14/77	C	0.24	0.28	49°	0.37
(28 days)	A	81.0	93.6	49°	124.0

*C = sandy clay and A = aquifer (sand-gravel).

†For the meaning of the negative sign, please refer to Figure 30.

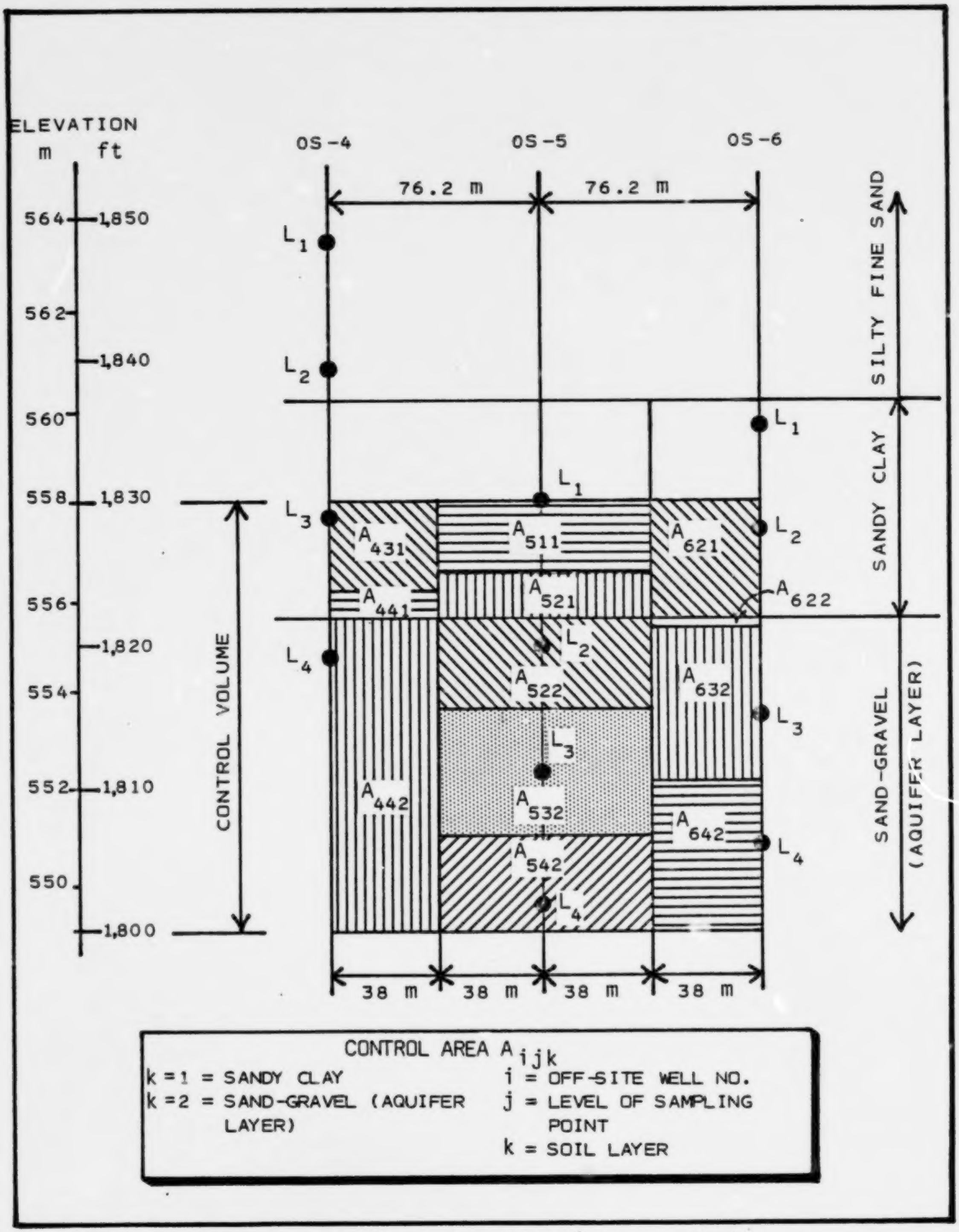

ELEVATION
m ft
564 1,850
562
1,840
560
558 1,830
556
1,820
554
552 1,810
550
1,800
OS-4
OS-5
OS-6
76.2 m
76.2 m
L_1
L_2
L_3
L_4
L_1
L_2
L_3
L_4
L_1
L_2
L_3
L_4
A_{431}
A_{441}
A_{442}
A_{511}
A_{521}
A_{522}
A_{532}
A_{542}
A_{621}
A_{622}
A_{632}
A_{642}
CONTROL VOLUME
SILTY FINE SAND
SANDY CLAY
SAND-GRAVEL (AQUIFER LAYER)
38 m
38 m
38 m
38 m
CONTROL AREA A_{ijk}
k = 1 = SANDY CLAY
k = 2 = SAND-GRAVEL (AQUIFER LAYER)
i = OFF-SITE WELL NO.
j = LEVEL OF SAMPLING POINT
k = SOIL LAYER

Figure 31. Inlet section of site 1 (perpendicular to x-direction).

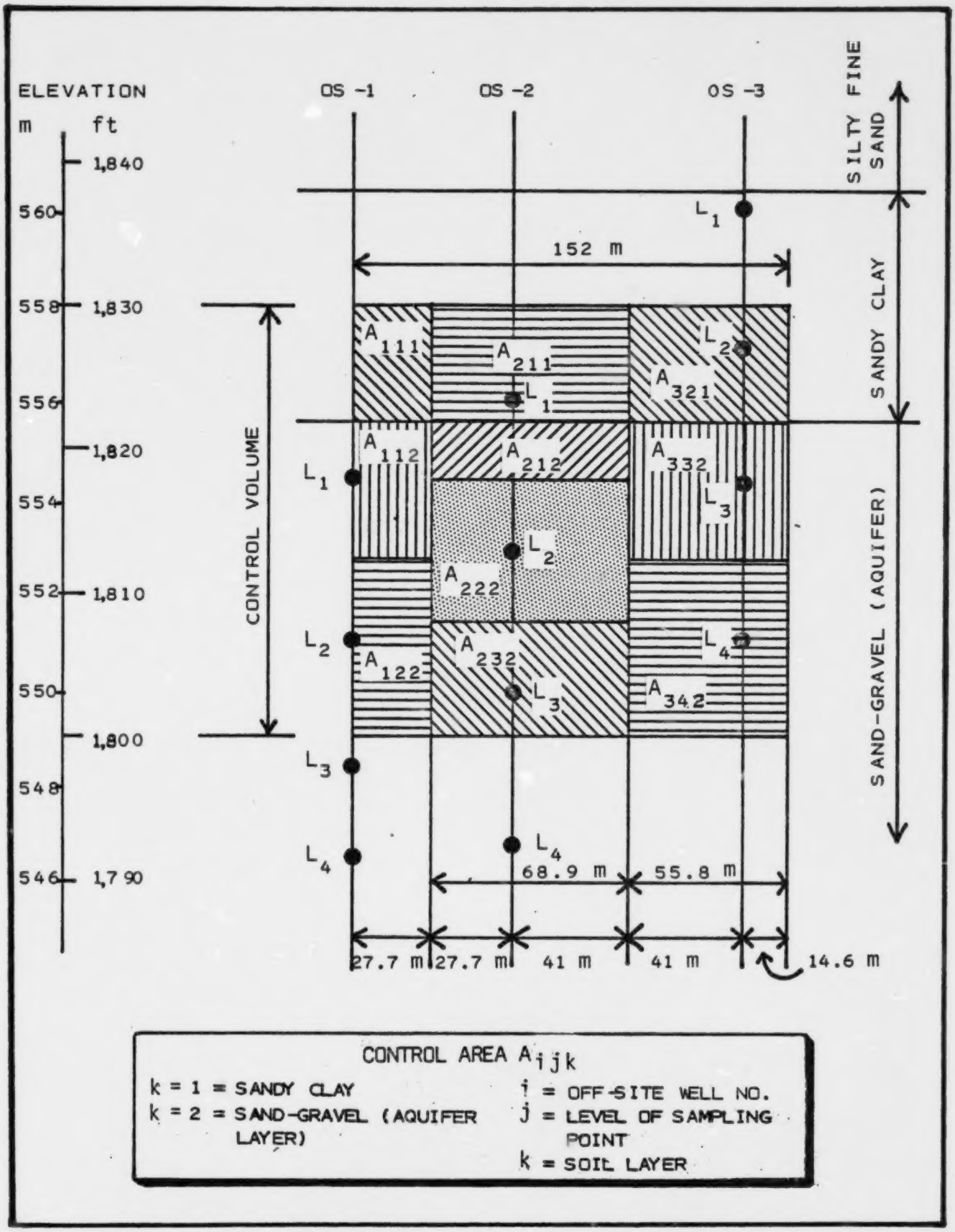

ELEVATION
m
ft
1,840
560
558
1,830
556
1,820
554
552
1,810
550
1,800
548
546
1,790
OS -1
OS -2
OS -3
SILTY FINE SAND
SANDY CLAY
SAND-GRAVEL (AQUIFER)
CONTROL VOLUME
152 m
L1
L2
L3
L4
A111
A211
A321
A112
A212
A332
A222
A122
A232
A342
68.9 m
55.8 m
27.7 m
27.7 m
41 m
41 m
14.6 m
CONTROL AREA Aijk
k = 1 = SANDY CLAY
k = 2 = SAND-GRAVEL (AQUIFER LAYER)
i = OFF-SITE WELL NO.
j = LEVEL OF SAMPLING POINT
k = SOIL LAYER

Figure 32. Outlet section of site 1 (perpendicular to x-direction).

TABLE 15. CONTAMINANT FLUX AND MASS THROUGH INLET FACE OF SITE 1
(Aquifer layer of control volume)

Period	Area symbol*	Area (m^2)	Q (m^3/d)	Cl⁻			$SO_4^=$			TOC		
				C (ppm)†	J (kg/d)#	M (kg)**	C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)
10/31/76	A442	256	2,120	57	12.2	501	260	55.7	2,280	73	15.6	641
	A522	151	1,250	30	3.80	156	220	27.8	1,140	381	48.2	19.8
	A532	209	1,730	29	5.08	208	220	38.6	1,580	144	25.2	1,040
12/11/76	A542	151	1,250	57	7.21	296	200	25.3	1,040	81	10.3	420
	A622	5.81	48.2	31	0.150	6.2	310	1.51	62.0	11	0.05	2.00
(41d)	A632	128	1,060	31	3.32	136	270	28.9	1,190	25	2.68	110
	A642	122	1,010	35	3.58	147	230	23.5	964	7	0.72	29.0
12/11/76	A442	256	2,080	65	13.67	888	100	21.0	1,370	8	1.68	109
	A522	151	1,230	38	4.72	307	35	4.35	283	77	9.57	622
1/21/77	A532	209	1,700	14	2.41	157	125	21.5	1,400	60	10.3	671
	A542	151	1,230	56	6.96	452	110	13.7	888	21	2.61	170
2/14/77	A622	5.81	47.3	37	0.18	11.5	90	0.430	28.0	4	0.020	1.00
	A632	128	1,040	24	2.52	164	255	26.8	1,740	12	1.26	82.0
(65d)	A642	122	992	34	3.41	222	240	24.1	1,570	4	0.40	26.0
2/14/77	A442	256	2,056	2	0.420	17.3	55	11.4	475	9	1.87	78.0
	A522	151	1,220	3	0.370	15.3	40	4.92	204	72	8.85	367
3/10/77	A532	209	1,700	5	0.850	35.3	70	11.9	494	16	2.72	113
	A542	151	1,220	24	2.95	122	190	23.4	969	4	0.49	20.0
3/28/77	A622	5.81	46.7	6	0.030	1.2	85	0.400	17.0	1	0.005	0.200
	A632	128	1,030	20	2.08	86.3	250	26.0	1,080	5	0.52	22.0
(41.5d)	A642	122	981	33	3.27	136	250	24.8	1,030	3	0.30	12.0
3/28/77	A442	256	2,056	22.5	4.68	81.9	150	31.2	546	7	1.46	25.0
	A522	151	1,220	7.5	0.920	16.1	50	6.14	108	40	4.92	86.0
	A532	209	1,700	14	2.38	41.7	120	20.4	357	10	1.70	30.0
4/14/77	A542	151	1,220	28	3.44	60.2	200	24.6	430	3	0.37	6.00
	A622	5.81	46.7	5	0.020	0.400	60	0.280	5.0	3	0.01	0.300
	A632	128	1,030	17	1.77	30.9	190	19.8	346	4	0.42	7.00
(17.5d)	A642	122	981	30	2.98	52.1	245	24.3	425	4	0.40	7.00
Sum - 165d	A_{in}	1,020.0	—	—	26.4‡	4,350	—	136‡	22,500	—	40.4‡	6,570

TABLE 15. (continued)

Period	Area symbol*	Soluble Fe C (ppm)	Soluble Fe J (kg/d)	Soluble Fe M (kg)	Soluble Hg C (ppm)	Soluble Hg J (kg/d)	Soluble Hg M (kg)	Soluble Pb C (ppm)	Soluble Pb J (kg/d)	Soluble Pb M (kg)	Soluble Zn C (ppm)	Soluble Zn J (kg/d)	Soluble Zn M (kg)
10/31/76	A442	7.20	1.54	63.1	0.0002	0.00004	0.002	0.010	0.002	0.082	0.17	0.040	1.64
	A522	0.13	0.020	0.8	0.0002	0.00003	0.001	0.005	0.0006	0.025	0.16	0.020	0.820
	A532	0.64	0.110	4.50	0.0002	0.000035	0.001	0.005	0.0009	0.037	0.05	0.009	0.370
12/11/76	A542	1.10	0.040	1.60	0.0002	0.000025	0.001	0.005	0.0006	0.025	0.01	0.001	0.040
	A622	0.01	0.00005	0.002	0.0003	0.000002	0.00008	0.005	0.00002	0.0008	0.01	0.00005	0.002
	A632	8.10	0.870	35.7	0.0002	0.00002	0.0008	0.210	0.022	0.900	0.71	0.080	3.28
(41d)	A642	16.0	1.63	67.0	0.0002	0.00002	0.0008	0.210	0.021	0.860	0.48	0.050	2.05
12/11/76	A442	47.0	9.90	644	0.0009	0.0002	0.013	0.005	0.001	0.065	0.01	0.002	0.130
	A522	1.30	0.160	10.4	0.0002	0.000025	0.002	0.005	0.0006	0.040	0.01	0.001	0.070
1/21/77	A532	1.20	0.210	13.7	0.0004	0.00007	0.0045	0.005	0.0009	0.060	0.03	0.005	0.330
	A542	0.66	0.080	5.20	0.0002	0.000025	0.002	0.005	0.0006	0.040	0.01	0.001	0.070
2/14/77	A622	0.01	0.00005	0.003	0.0002	0.000001	0.00007	0.005	0.00002	0.0013	0.01	0.00005	0.003
	A632	3.50	0.004	0.30	0.0003	0.00003	0.002	0.085	0.009	0.600	0.30	0.030	1.95
(65d)	A642	6.80	0.680	44.0	0.0003	0.00003	0.002	0.085	0.0085	0.550	0.20	0.020	1.30
2/14/77	A442	152	31.6	1,310	0.0010	0.0002	0.008	0.009	0.002	0.083	0.04	0.008	0.330
	A522	31.0	3.81	158	0.0007	0.00009	0.004	0.005	0.0006	0.025	0.02	0.002	0.080
3/10/77	A532	1.40	0.240	10.0	0.0005	0.000085	0.0035	0.005	0.00085	0.035	0.02	0.003	0.120
	A542	0.32	0.040	1.70	0.0005	0.00006	0.0025	0.005	0.0006	0.025	0.01	0.001	0.040
3/28/77	A622	0.90	0.004	0.17	0.0004	0.000002	0.00008	0.005	0.00002	0.0008	0.01	0.00005	0.002
	A632	0.44	0.05	2.10	0.0003	0.00003	0.0012	0.005	0.0005	0.021	0.03	0.003	0.124
(41.5d)	A642	0.05	0.005	0.210	0.0004	0.00004	0.002	0.005	0.0005	0.021	0.03	0.003	0.124
3/28/77	A442	77.0	5.99	105	0.0007	0.00014	0.0025	0.035	0.007	0.120	0.27	0.060	1.05
	A522	15.8	1.94	34.0	0.0006	0.00007	0.001	0.060	0.007	0.120	0.11	0.014	0.250
	A532	8.80	1.50	26.3	0.00035	0.00006	0.001	0.020	0.003	0.050	0.07	0.010	0.175
4/14/77	A542	4.50	0.550	10.0	0.00035	0.00004	0.0007	0.005	0.0006	0.010	0.18	0.020	0.350
	A622	7.00	0.030	0.500	0.00025	0.000001	0.00002	0.135	0.0006	0.010	0.14	0.0007	0.010
	A632	6.00	0.620	11.0	0.00025	0.00003	0.0005	0.070	0.007	0.120	0.78	0.080	1.40
(17.5d)	A642	1.20	0.120	2.10	0.0003	0.00003	0.0005	0.005	0.0005	0.009	0.05	0.005	0.090
Sum - 165d	A_{in}	—	15.5‡	2,560	—	0.00047	0.0778	—	0.024	3.94	—	0.095	15.6

*Area symbol A_{ijk}: where i = offsite well number; j = level of sampling point in well; and k = soil layer if k = 1 = sandy clay and k = 2 = sand-gravel (aquifer layer).

†Concentrations of constituents on 4/14/77 are from concentration versus time diagram (see Figures 20 to 26).

‡Contaminant flux (J) = C (ppm) x Q (m^3/d) x 10^{-3} (unit = kg/d).

**Input mass (M) through inlet section = J x Period (unit = kg).

‡Average value.

TABLE 16. CONTAMINANT FLUX AND MASS THROUGH OUTLET FACE OF SITE 1
(Aquifer layer of control volume)

Period	Area symbol*	Area (m^2)	Q (m^3/d)	Cl^- C (ppm)†	Cl^- J (kg/d)#	Cl^- M (kg)**	$SO_4^=$ C (ppm)	$SO_4^=$ J (kg/d)	$SO_4^=$ M (kg)	TOC C (ppm)	TOC J (kg/d)	TOC M (kg)
1/3/77	A112	80.3	655	16	1.06	9.50	67.5	4.46	40.0	9	0.590	5
	A122	106	860	25	2.14	19.3	135	11.7	106	15	1.30	12
	A212	84	683	29	2.00	18.0	290	20.1	180	16	1.11	10
	A222	210	1,710	21	3.63	32.7	230	39.8	358	4	0.690	6
1/12/77	A232	168	1,370	32	4.42	39.8	350	48.4	436	7	0.970	9
	A332	170	1,380	32	4.48	40.3	150	21.0	189	11	1.54	14
(9d)	A342	204	4,660	15	2.52	22.7	250	42.0	378	16	2.69	24
1/12/77	A112	80.3	665	13	0.860	28.4	40	2.64	87.0	5	0.330	11
	A122	106	860	24	2.06	68.1	100	8.70	287	6	0.520	17
1/21/77	A212	84	683	28	1.94	63.9	280	19.4	640	7	0.480	16
	A222	210	1,710	17	2.94	97.0	210	36.3	1,200	4	0.690	23
2/14/77	A232	168	1,370	31	4.29	141	350	48.4	1,600	4	0.550	18
	A332	70	1,380	27	3.78	125	130	18.2	601	5	0.700	23
(33d)	A342	204	1,660	15	2.52	83.1	250	42.0	1,400	13	2.18	72
2/14/77	A112	80.3	646	6	0.390	23.1	6	0.390	23.0	4	0.260	15
	A122	106	850	16	1.38	81.2	15	1.29	76.0	5	0.430	25
3/10/77	A212	84	676	17	1.16	68.6	90	6.15	363	2	0.140	8
	A222	210	1,690	21	3.59	212	130	22.2	1,310	3	0.510	30
4/14/77	A232	168	1,350	21	2.87	169	300	41.0	2,420	5	0.680	40
	A332	170	1,370	17	2.35	139	180	24.9	1,420	3	0.420	24
(59d)	A342	204	1,640	15	2.49	147.0	250	41.5	2,450	3	0.500	29
4/14/77	A112	80.3	658	11	0.730	36.4	35	2.33	116	3	0.200	10
	A122	106	866	15	1.31	65.2	115	10.1	501	4	0.350	17
5/19/77	A212	84	688	5	0.350	17.3	35	2.44	121	2	0.140	7
	A222	210	1,720	10	1.74	86.4	100	17.4	864	2	0.350	17
6/3/77	A232	168	1,380	24	3.34	166	265	36.9	1,830	3	0.420	21
	A332	170	1,390	8	1.13	56.0	80	11.3	560	3	0.420	21
(49.64d)	A342	204	1,670	28	4.74	235	275	46.5	2,310	6	1.01	50
6/3/77	A112	80.3	658	8.5	0.570	8.30	19	1.27	19.0	3	0.200	3
	A122	106	866	15	1.31	19.2	64	5.61	82.0	4.5	0.390	6
	A212	84	688	5	0.350	5.10	60	4.18	61.0	1.5	0.100	2
	A222	210	1,720	10	1.74	25.5	113	19.7	288	2.5	0.440	6
6/17/77	A232	168	1,380	25	3.48	51.0	280	39.0	571	4	0.560	8
	A332	170	1,390	8	1.13	16.5	130	18.3	268	3	0.420	6
(14.64d)	A342	204	1,670	27	4.57	66.9	260	44.0	644	4.5	0.760	11
Sum 165.28d	A_{out}	1,020	--	--	15.0‡	2,480	--	144‡	23,800	--	3.73‡	616

TABLE 16. (continued)

Period	Area symbol*	Soluble Fe			Soluble Hg			Soluble Pb			Soluble Zn		
		C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)
1/3/77	A112	0.40	0.030	0.270	0.0016	0.00010	0.00090	0.065	0.0043	0.039	0.03	0.002	0.018
	A122	0.40	0.035	0.315	0.00044	0.00004	0.00036	0.075	0.0065	0.059	0.06	0.005	0.045
	A212	5.00	0.300	2.70	0.00026	0.00002	0.00018	0.010	0.0007	0.006	0.85	0.060	0.540
	A222	1.00	0.200	1.80	0.00020	0.00003	0.00027	0.015	0.003	0.027	0.15	0.030	0.270
1/12/77	A232	12.0	1.66	15.0	0.00020	0.00003	0.00027	0.330	0.045	0.400	0.66	0.090	0.810
	A332	1.20	0.170	1.53	0.0003	0.00004	0.00036	0.025	0.0035	0.030	0.10	0.014	0.130
(9d)	A342	1.20	0.200	1.80	0.0004	0.00007	0.00064	0.015	0.0025	0.020	0.06	0.010	0.090
1/12/77	A112	0.01	0.0007	0.023	0.0020	0.00013	0.0043	0.005	0.0003	0.010	0.01	0.0007	0.023
	A122	0.01	0.0009	0.030	0.0005	0.00004	0.0013	0.006	0.0005	0.016	0.01	0.0009	0.030
1/21/77	A212	0.10	0.007	0.230	0.0003	0.00002	0.0007	0.005	0.0003	0.010	0.58	0.040	1.32
	A222	0.01	0.002	0.066	0.0002	0.00003	0.0010	0.005	0.0009	0.030	0.01	0.002	0.07
2/14/77	A232	16.0	2.21	72.9	0.0002	0.00003	0.0010	0.380	0.053	1.75	0.87	0.120	3.96
	A332	0.24	0.030	1.00	0.0002	0.00003	0.0010	0.005	0.0007	0.023	0.01	0.0005	0.016
(33d)	A342	0.90	0.150	4.95	0.0002	0.00003	0.0010	0.010	0.0017	0.056	0.05	0.008	0.26
2/14/77	A112	3.30	0.210	12.4	0.0009	0.00006	0.004	0.360	0.024	1.42	0.06	0.004	0.240
	A122	4.60	0.400	23.6	0.0004	0.00003	0.002	0.080	0.007	0.410	0.06	0.005	0.300
3/10/77	A212	23.0	1.57	92.6	0.0002	0.00014	0.008	0.170	0.012	0.710	0.95	0.070	4.13
	A222	6.10	1.04	61.4	0.0006	0.00010	0.006	0.050	0.0085	0.500	0.18	0.031	1.83
4/14/77	A232	23.0	3.14	185	0.0008	0.00011	0.007	0.360	0.049	2.89	0.72	0.100	5.90
	A332	5.80	0.800	47.2	0.0010	0.00014	0.008	0.030	0.004	0.240	0.14	0.020	1.18
(59d)	A342	0.01	0.002	0.120	0.0006	0.00010	0.006	0.005	0.0008	0.050	0.02	0.003	0.180
4/14/77	A112	6.80	0.450	223	0.0002	0.00001	0.0005	0.730	0.050	2.48	0.10	0.007	0.350
	A122	39.0	3.42	170	0.0002	0.00002	0.0010	0.100	0.009	0.45	0.46	0.040	2.00
5/19/77	A212	27.0	1.88	93.3	0.0017	0.00012	0.0060	0.280	0.020	1.00	0.45	0.031	1.54
	A222	36.0	6.27	311	0.0002	0.00004	0.0020	0.320	0.056	2.78	0.40	0.070	3.48
6/3/77	A232	47.0	6.55	325	0.0002	0.00003	0.0015	0.330	0.046	2.28	0.65	0.090	4.50
	A332	24.0	3.38	168	0.0004	0.00006	0.0030	0.245	0.035	1.74	1.00	0.140	7.00
(49.64d)	A342	25.0	4.23	210	0.0006	0.00010	0.0050	0.105	0.018	0.89	0.25	0.040	2.00
6/3/77	A112	3.80	0.250	0.017	0.0002	0.00001	0.0002	0.400	0.027	0.400	0.11	0.007	0.100
	A122	21.3	1.87	27.4	0.0002	0.00002	0.0003	0.080	0.007	0.100	0.25	0.022	0.320
	A212	34.0	2.37	34.7	0.0009	0.00006	0.0009	0.170	0.012	0.180	0.80	0.060	0.880
	A222	24.0	4.18	61.2	0.0002	0.00004	0.0006	0.185	0.032	0.470	0.25	0.044	0.640
	A232	52.0	7.24	106	0.0002	0.00003	0.0004	0.310	0.043	0.630	0.60	0.084	1.23
6/17/77	A332	21.6	3.05	44.6	0.0003	0.00004	0.0006	0.165	0.023	0.340	0.18	0.025	0.37
(14.64d)	A342	14.2	2.40	35.1	0.0004	0.00007	0.0010	0.060	0.010	0.150	0.12	0.020	0.30
Sum 165.28d	A_{out}	--	12.9‡	2130	--	0.00047‡	0.0773	--	0.137‡	22.6	--	0.280‡	46.1

* Area symbol A_{ijk}: where i = offsite well number; j = level of sampling point in well; and k = soil layer if k = 1 = sandy clay and k = 2 = sand-gravel.

† Concentrations of constituents on 1/3/77 and 6/17/77 are from concentration versus time diagram (see Figures 20 to 26).

# Contaminant flux (J) = C (ppm) x Q (m^3/d) x 10^{-3} (unit = kg/d).

** Output mass (M) through outlet section = J x Period (unit = kg).

‡ Average value.

To ascertain the amount of contaminant attenuation or elution in the special control volume, travel time (time lag) between the inlet and outlet boundaries must be determined. From the control volume selected, there are two soil strata: sandy clay and sand-gravel aquifer. Using Equation 45, the travel time necessary for crossing the two boundaries of the aquifer layer was determined to be about 64 days; however, for the sandy clay layer, it was as long as 58 years. Since the experimental period was only 318 days, it was not possible to perform mass balance calculations on the sandy clay layer. Therefore, only the sand-gravel aquifer layer has been evaluated for attenuation or elution of contaminants.

The input time period (Tp) used was 165 days. For output time period, Tpl was calculated for the aquifer layer to be 165.28 days. The time lag (travel time, T) between the two boundaries of this soil layer was about 64 days, again using Equation 45. Using this information, the total input and output mass of the control volume for the designated time period was obtained by solving Equations 39 or 40. Results are listed in Tables 15 and 16. The difference between the input and output mass indicated attenuation or elution of contaminants (Equation 38). Seven contaminants were evaluated and the results are summarized below:

Item	Unit Input Mass	Unit Output Mass	Attenuation (+) or Elution (-)	Percent Change
Cl^-	498	285	+213	+ 43
SO_4^{2-}	2,595	2,719	-194	- 8
TOC	763	71	+692	+ 91
Fe	293	244	+ 49	+ 17
Hg	0.008	0.008	0	0
Pb	0.459	2.58	- 2.12	-460
Zn	1.80	5.37	- 3.57	-196

Units are in mg/d/m^3 of soil in aquifer layer, assuming a 53,000 m^3 control volume.

It can be seen that soluble chloride, TOC, and iron were attenuated by the aquifer layer at the rate of 213, 692, and 49 mg/day/m^3, respectively. This corresponds to 43, 91, and 17 percent removal efficiency, respectively. However, soluble sulfate, lead, and zinc were found to be eluted at 8, 460, and 196 percent, respectively, from this stratum.

As suggested by Lu (7), in an oxidizing environment, soluble iron may be removed from solution while soluble lead and zinc may be released into solution due to solid transformation, solubilization, and complexation. The reducing species from the landfill or those formed by the reducing leachate (with high sulfide content) changed upon contact with an aerobic regional groundwater. Generally, solid transformation is usually accompanied by a release of sulfate ions due to the oxidation of the reducing sulfide solids, as shown by the following examples:

$$\mathrm{MS(s)} + 2\ \mathrm{O_2} + \mathrm{CO_2} + \mathrm{H_2O} = 2\ \mathrm{CaCO_3} \longrightarrow$$
$$2\ \mathrm{Ca^{2+}} + \mathrm{SO_4^{2-}} + 2\ \mathrm{HCO_3^-} + \mathrm{MCO_3(s)} \qquad (47)$$

$$4\mathrm{FeS} + 9\ \mathrm{O_2} + 10\ \mathrm{H_2O} + 8\ \mathrm{CaCO_3} \longrightarrow 4\ \mathrm{Fe(OH)_3(s)}$$
$$+4\ \mathrm{SO_4^{2-}} + 8\ \mathrm{Ca^{2+}} + 8\ \mathrm{HCO_3^-} \qquad (48)$$

MS(s), metallic sulfide, has a higher solubility than $\mathrm{MCO_3(s)}$, metallic carbonate.

The attenuation or elution of each contaminant studied may be explained as follows:

Chloride--The reasons for the attenuation of chloride are not known, although dilution and anion exchange may account in part for the decrease of chloride concentration in the control volume. However, theoretically, it is not valid to consider dilution as a factor in the Site 1 control volume analysis since the dilute water volume was fixed.

Sulfate--As discussed above, the transformation of sulfide solid species to relatively oxidized solid species might be an important factor in increasing the sulfate levels in groundwater. Oxidation of the soluble sulfide species from the leachate may also result in increased sulfate levels.

TOC--The TOC levels in the groundwater of the control volume were greatly decreased following the first sampling. The attenuation of TOC by soil may be due partly to the microbial metabolism and in part to the surface sorption and chelation with clay minerals or solid organic species in the soil.

Soluble iron--Soluble iron in the control volume was attenuated, probably as a result of oxidation that converted the divalent iron species (either solid or soluble) to the relatively less soluble trivalent species.

Soluble mercury--Soluble mercury was unchanged in the control volume. As suggested by Lu (7), mercury in the solid phase is one of the most stable metallic solids. Its original stable form can be retained through sulfide competition, extremely low solubility, and strong adsorption and complexation capabilities.

Soluble lead--Soluble lead was eluted from the control volume soil. As shown in Equation 47, solid transformation of lead could lead to more soluble lead solid(s), which may be one of the primary factors in releasing lead from soil into groundwater. The formation of soluble carbonate complexes may also contribute to some lead elution. However, information on important ligands of lead in the control volume is lacking, so a detailed evaluation is impossible.

Soluble zinc--It is speculated that the mechanisms responsible for the transformation and complexation are believed to be the most important factors for this elution.

Observations on Concentration Isopleths and Related Factors

As illustrated in Figure 1, six new off-site plume wells were placed in two parallel lines approximately 46 m apart and perpendicular to the direction of groundwater flow. The wells in each line were spaced about 76 m apart on center. Wells 4, 5, and 6 were in Line 1, and Wells 1, 2, and 3 in Line 2. There were four sampling depths in each monitoring well.

A selected number of concentration isopleths depicting the changes in concentrations of specific contaminants monitored were used to describe certain trends observed during the Phase II monitoring (Figures 33 to 44). The columns on the right-hand side show the fine sand, clay, and sand-gravel strata for Line 1 and clay and sand-gravel strata for Line 2. These concentration isopleths were also used to assess the required frequency of monitoring, as well as the planned locations and depths at which monitoring wells should be placed.

Considerable similarities existed between the concentration isopleths for lead, iron, cadmium, zinc, copper, chromium, and nickel. No discernible correlation was observed between mercury and the above heavy metals.

The lead concentration isopleths indicated that the leachate occurred in one or more distinct, strong, concentrated plumes as identified by concentric regions of increasing or decreasing concentration (Figure 34). The July 1977 results of iron also indicated three separate, strong leachate plumes occurring in different sectors of the monitoring grid corresponding to different soil strata (Figure 33).

There were wide fluctuations in lead concentrations. While at one sampling, the concentrations were among the highest observed throughout the year-long period, in the next sampling they were less than the detection limit. The high concentration may be associated with the large volume of leachate generated and the low concentration may have resulted from a dilution effect or complex redux conditions under which lead was tied up in the

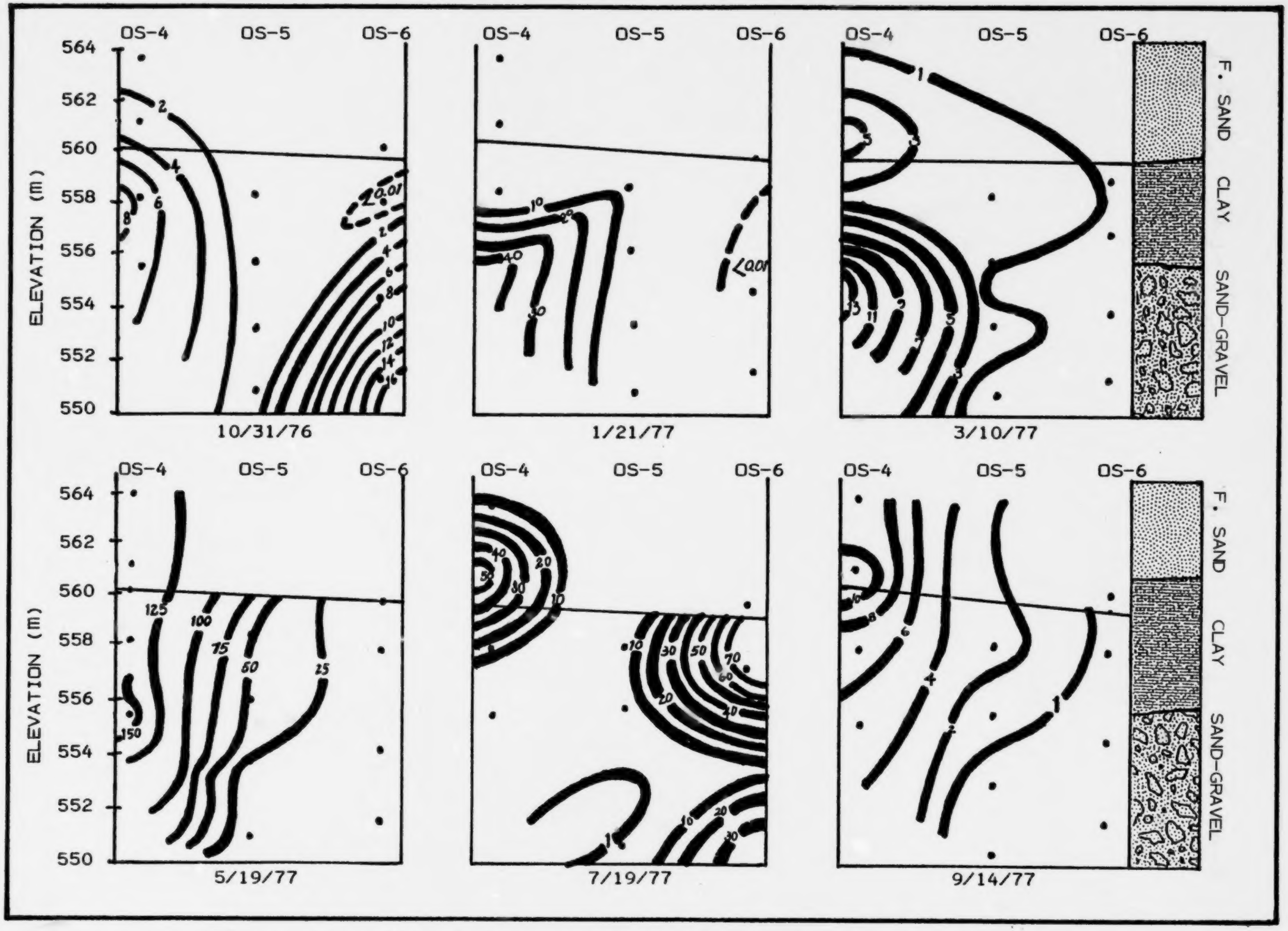


Figure 33a. Site 1 iron concentration isopleths for line 1.

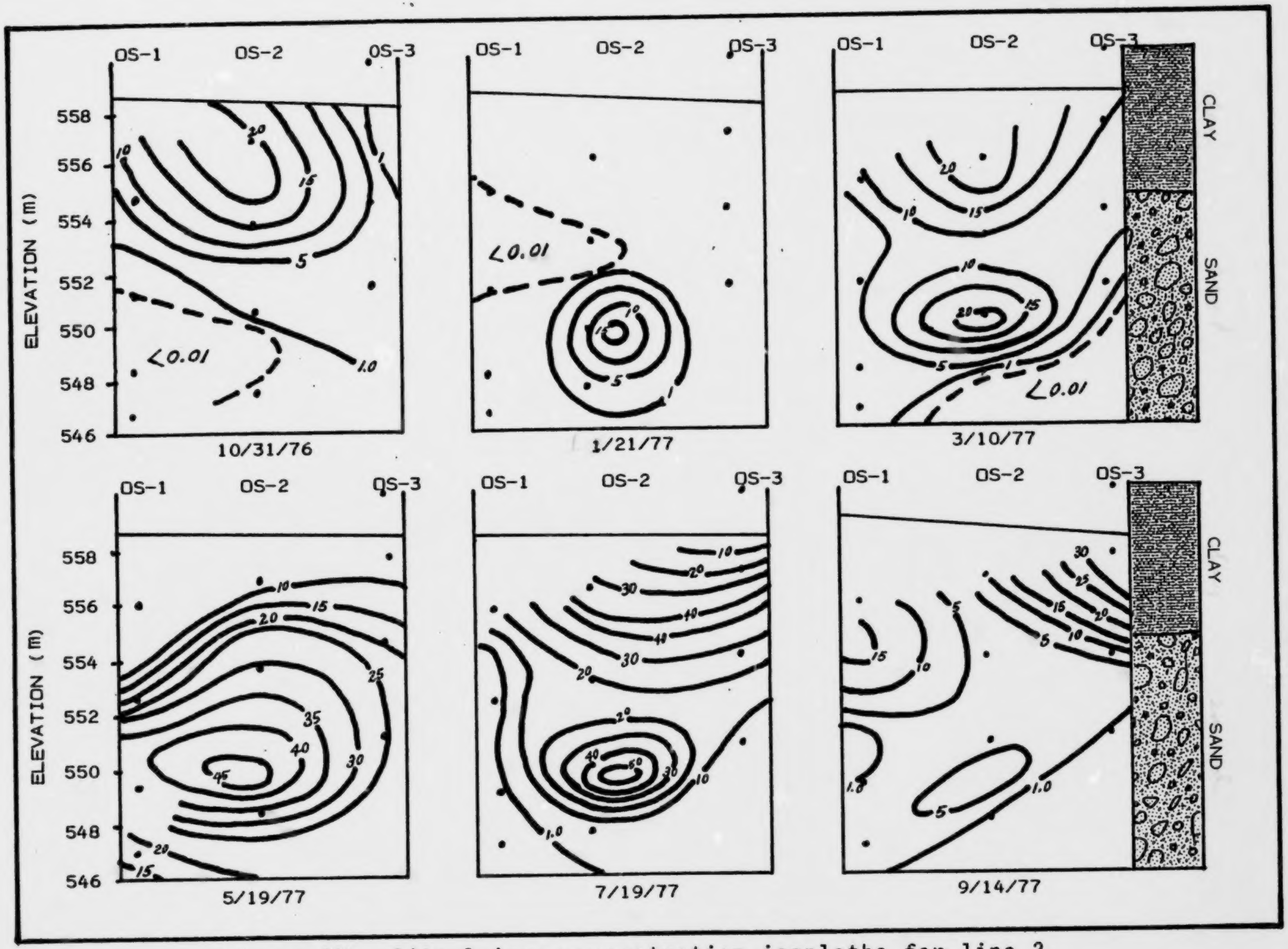


Figure 33b. Site 1 iron concentration isopleths for line 2.

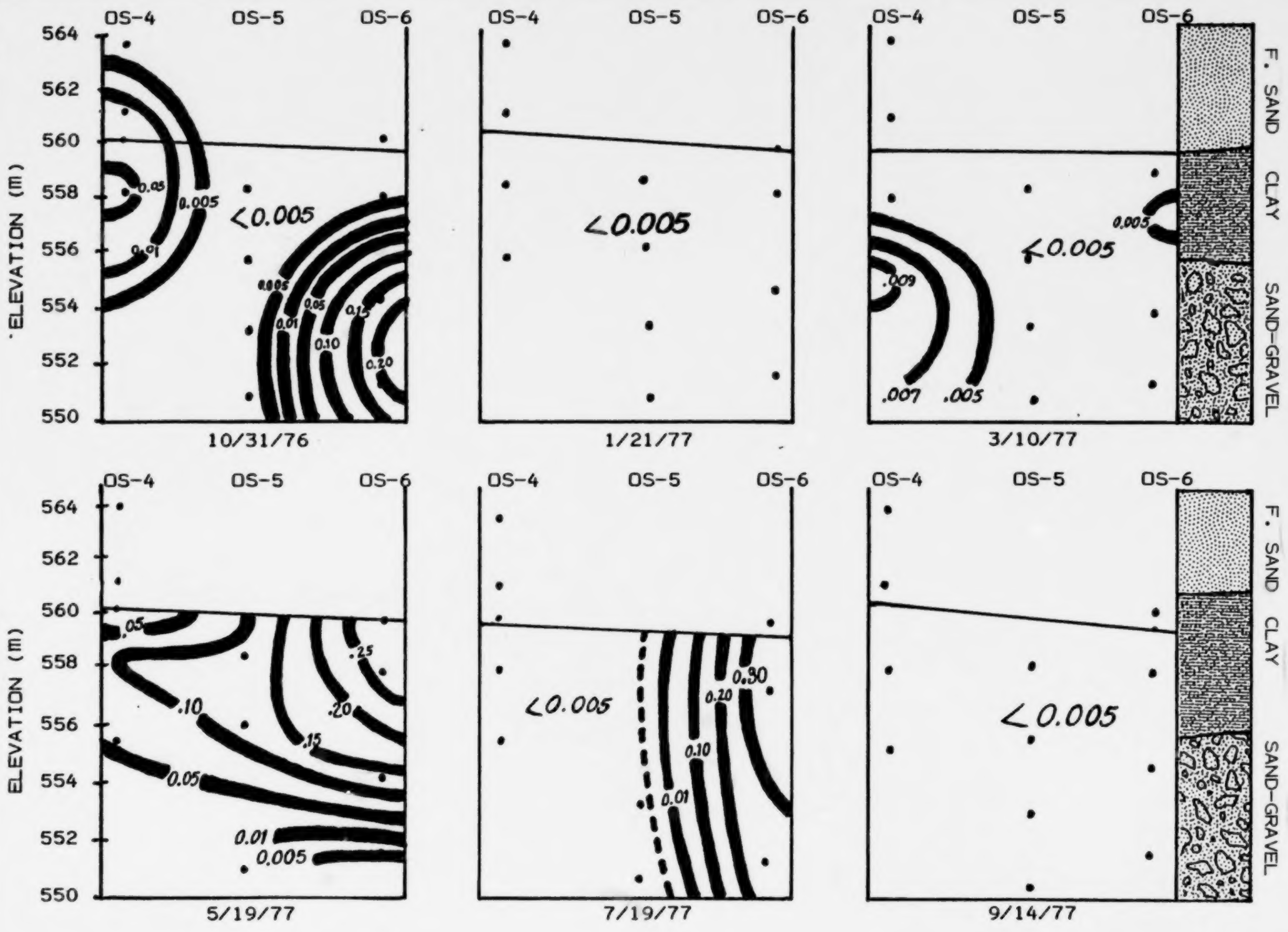


Figure 34a. Site 1 lead concentration isopleths for line 1.

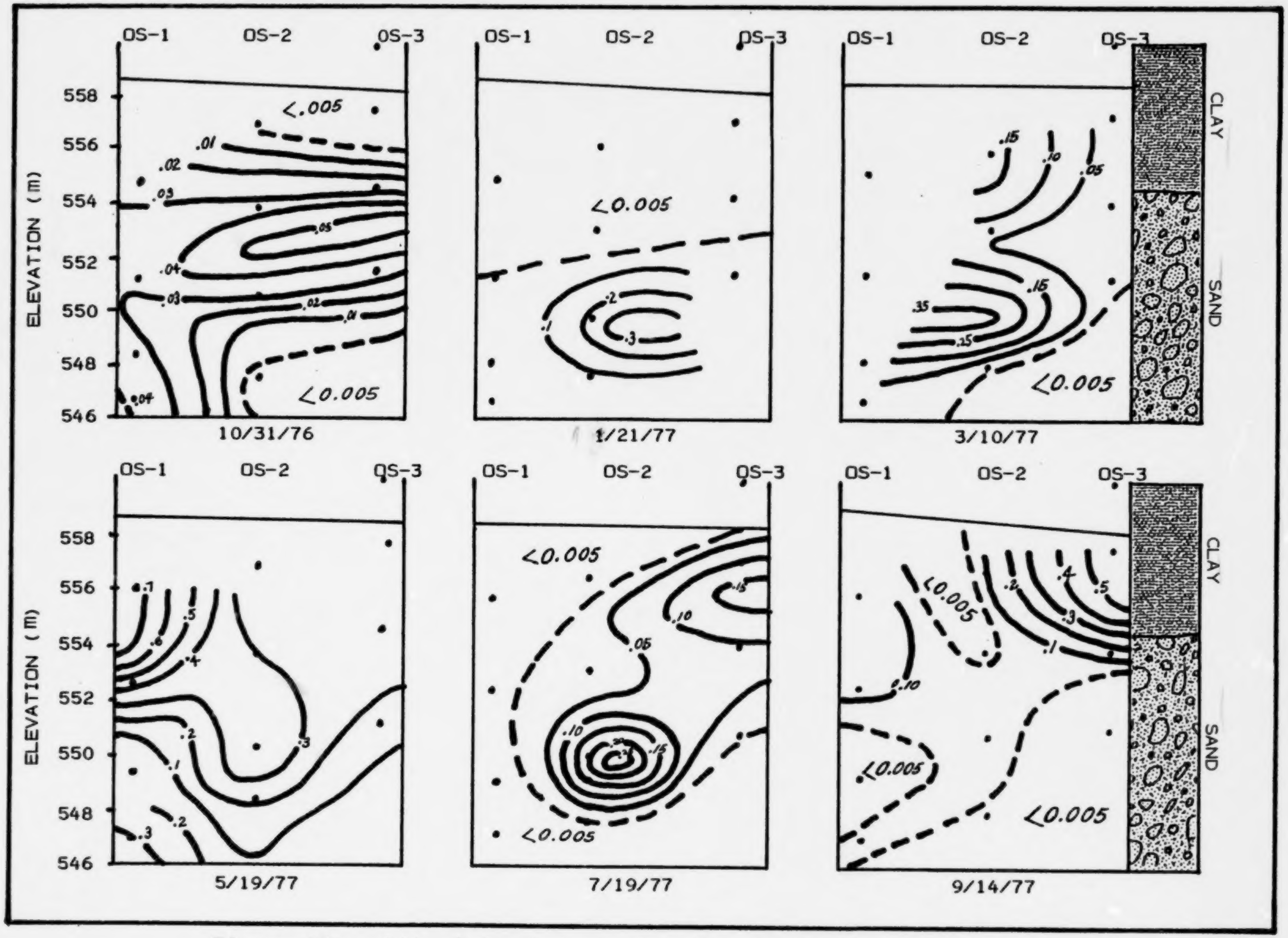


Figure 34b. Site 1 lead concentration isopleths for line 2.

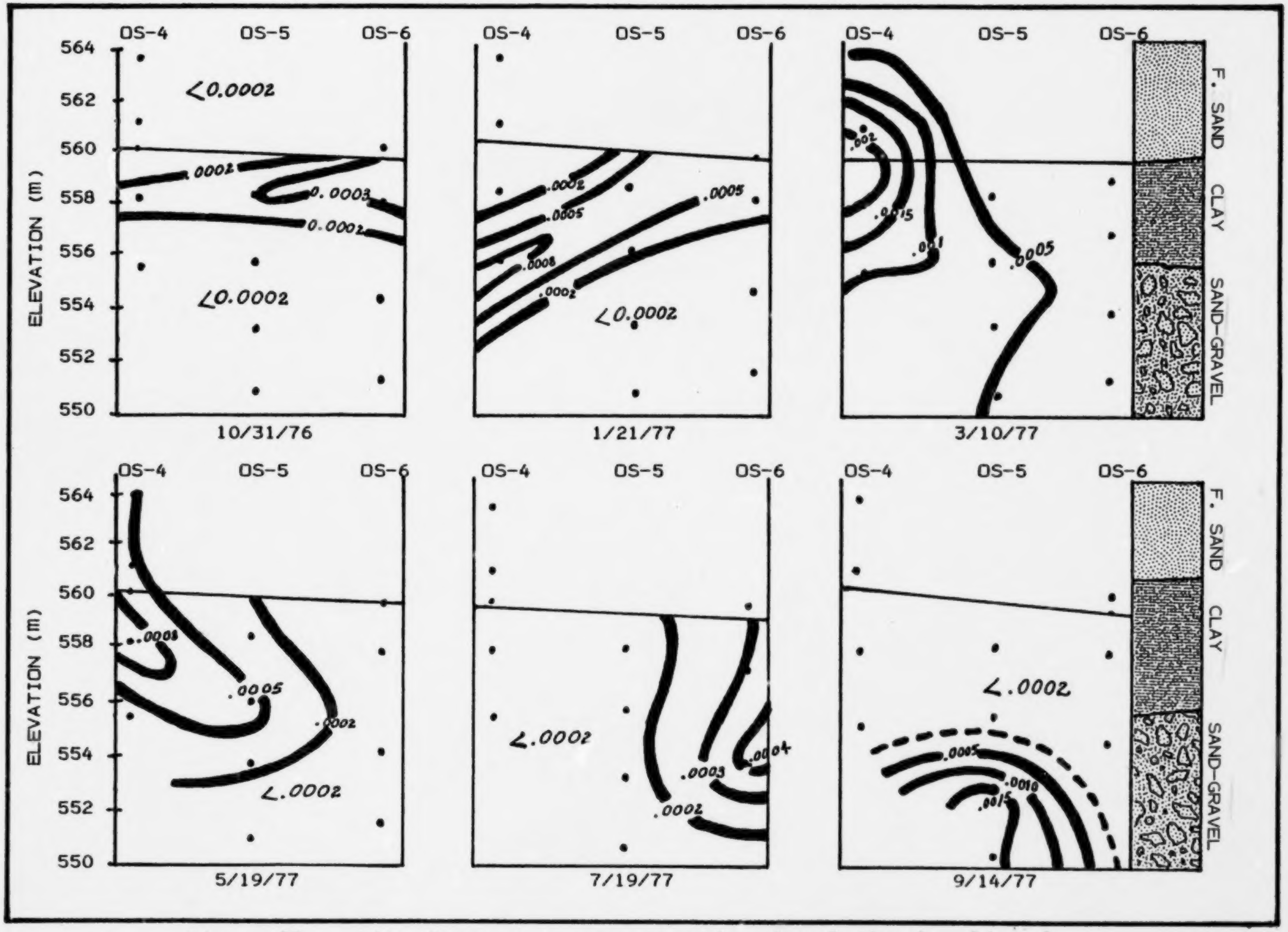


Figure 35a. Site 1 mercury concentration isopleths for line 1.

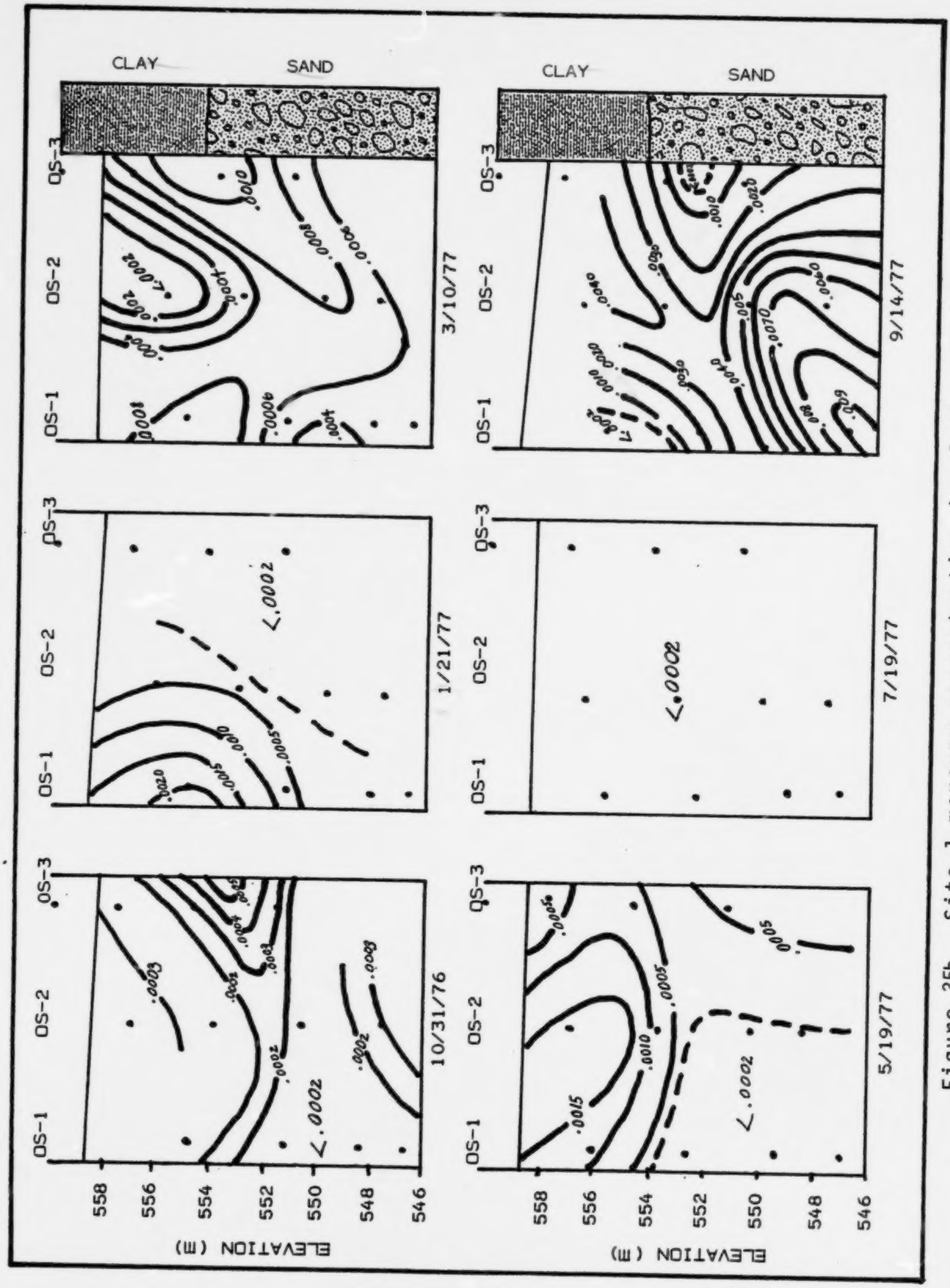


Figure 35b. Site 1 mercury concentration isopleths for line 2.

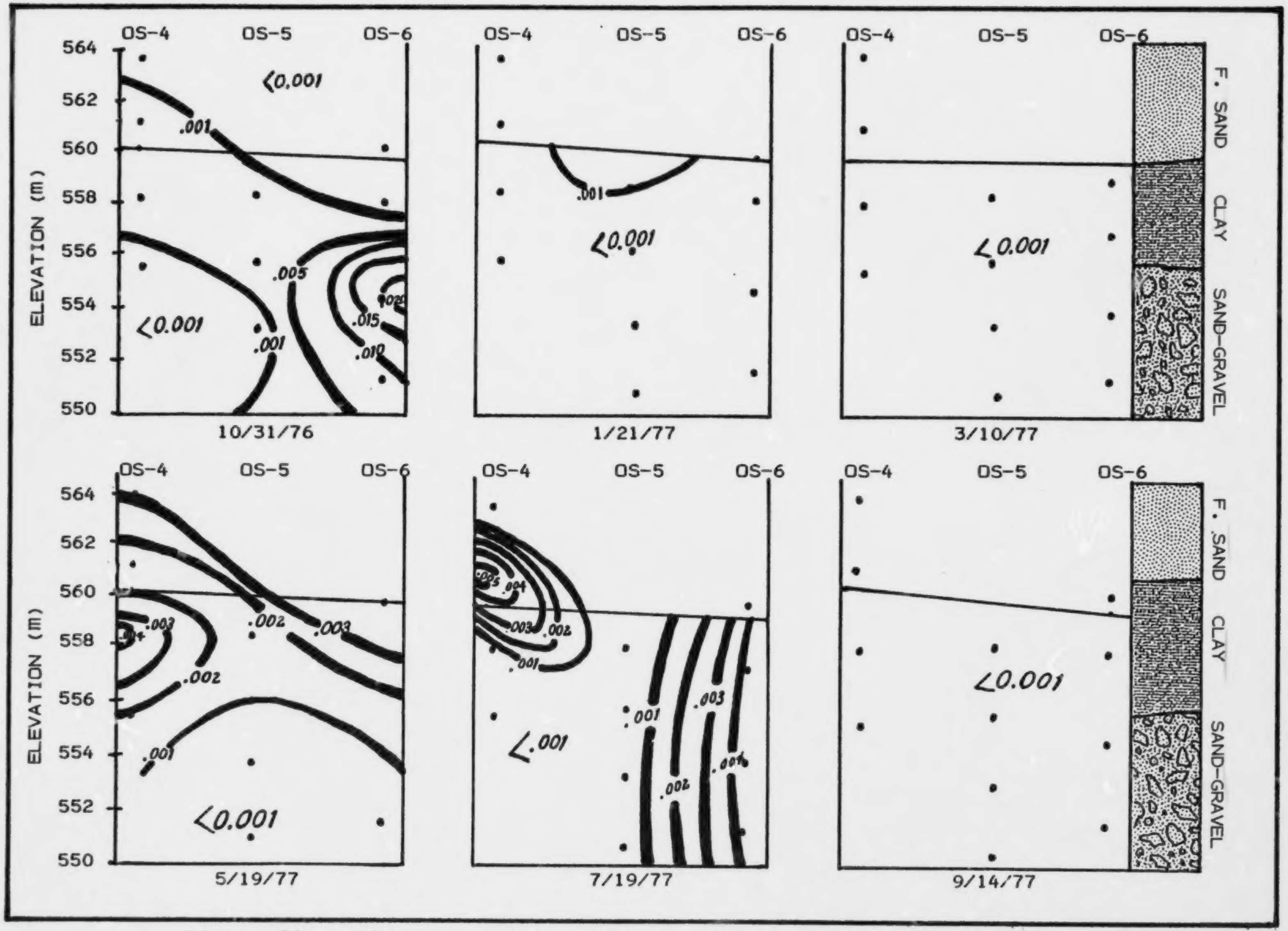


Figure 36a. Site 1 cadmium concentration isopleths for line 1.

36a

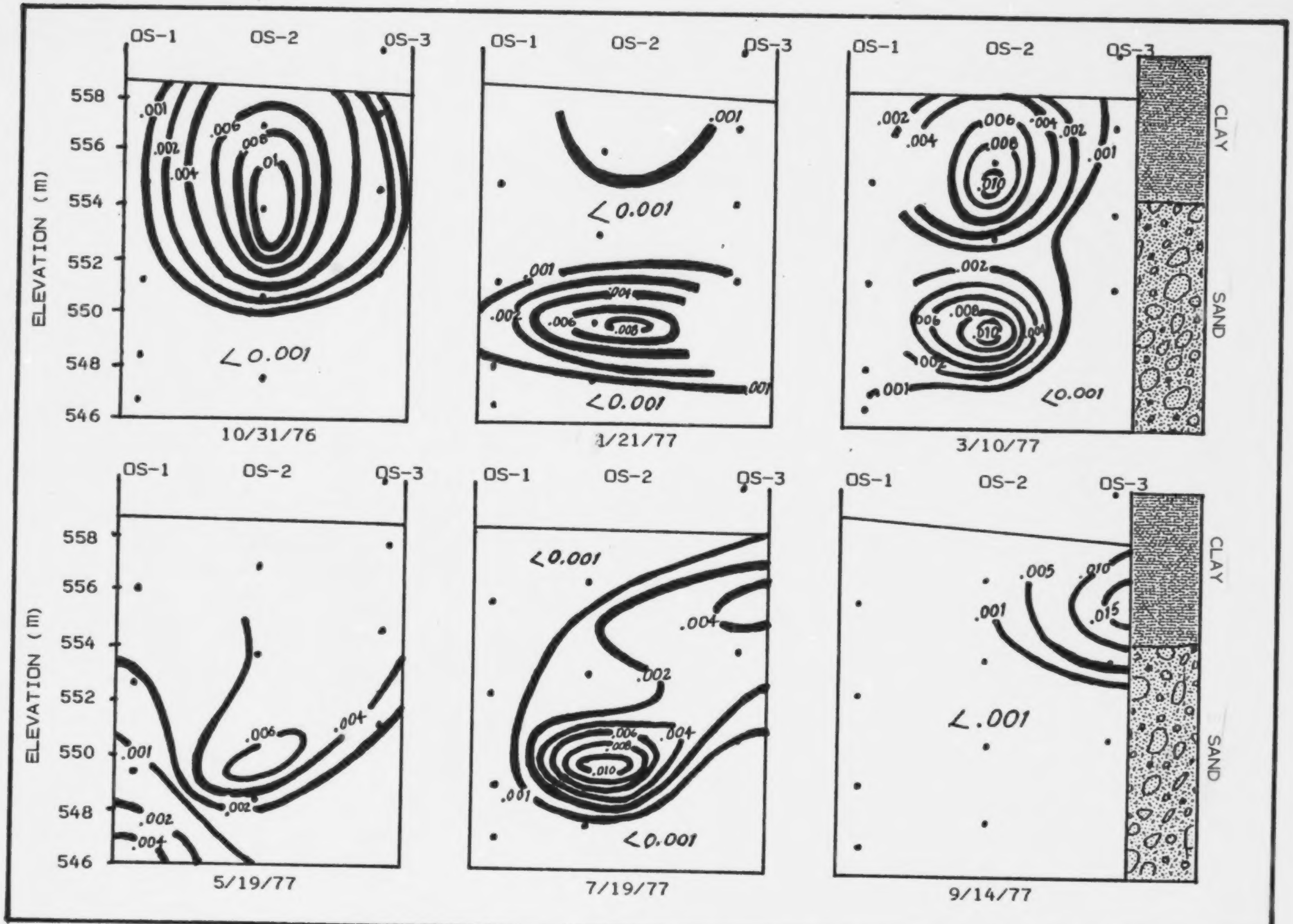


Figure 36b. Site 1 cadmium concentration isopleths for line 2.

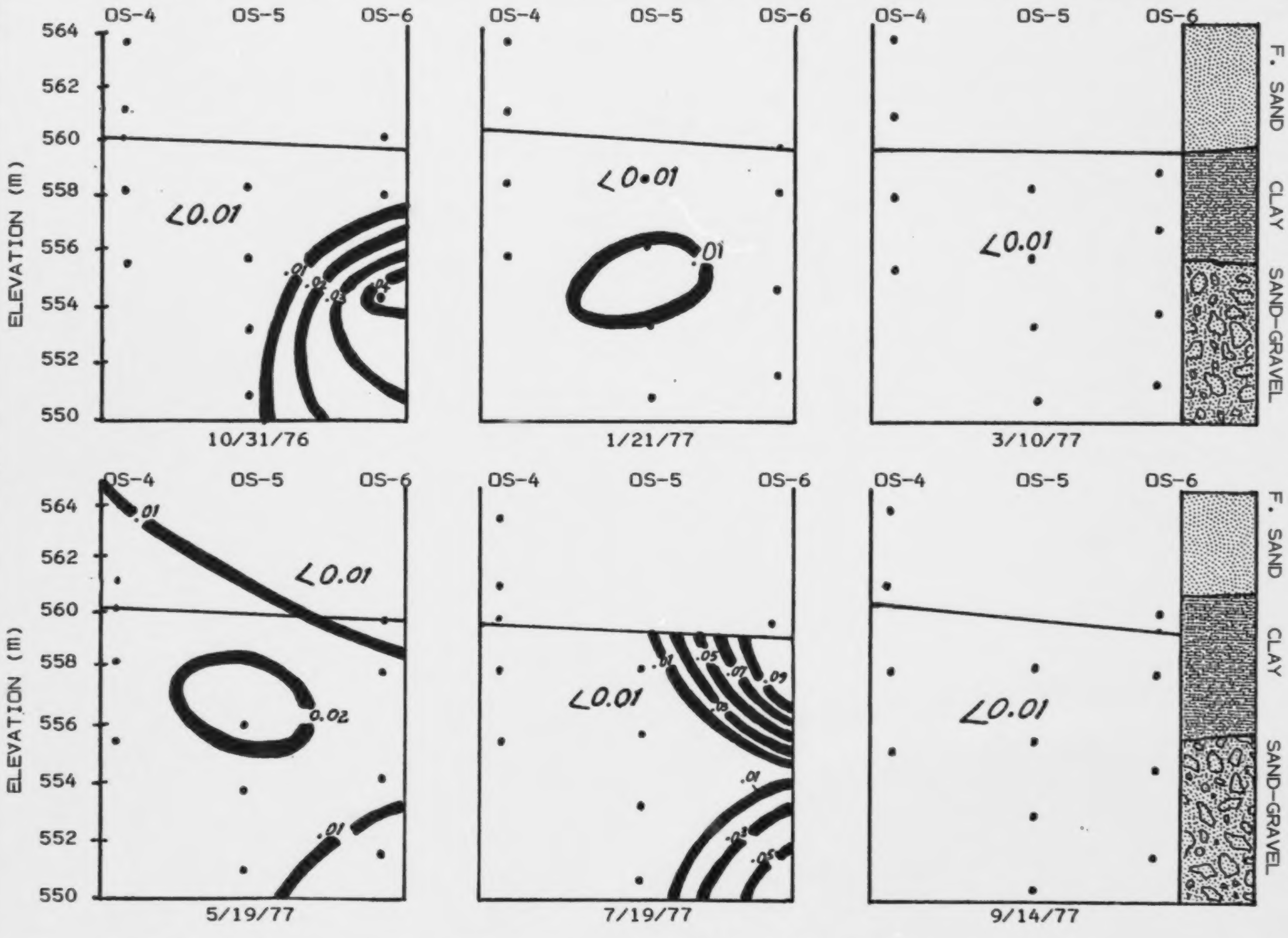


Figure 37a. Site 1 chromium concentration isopleths for line 1.

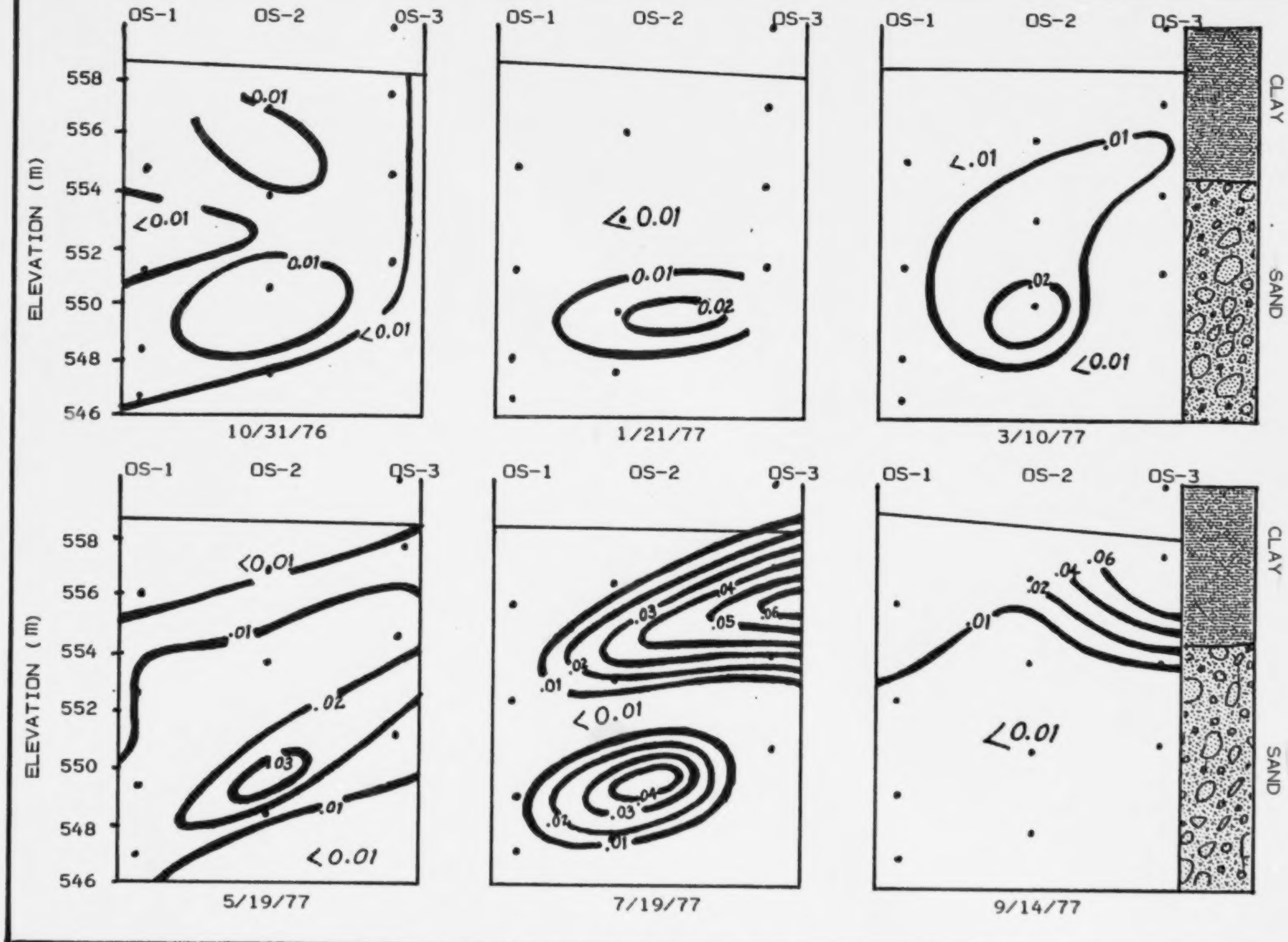


Figure 37b. Site 1 chromium concentration isopleths for line 2.

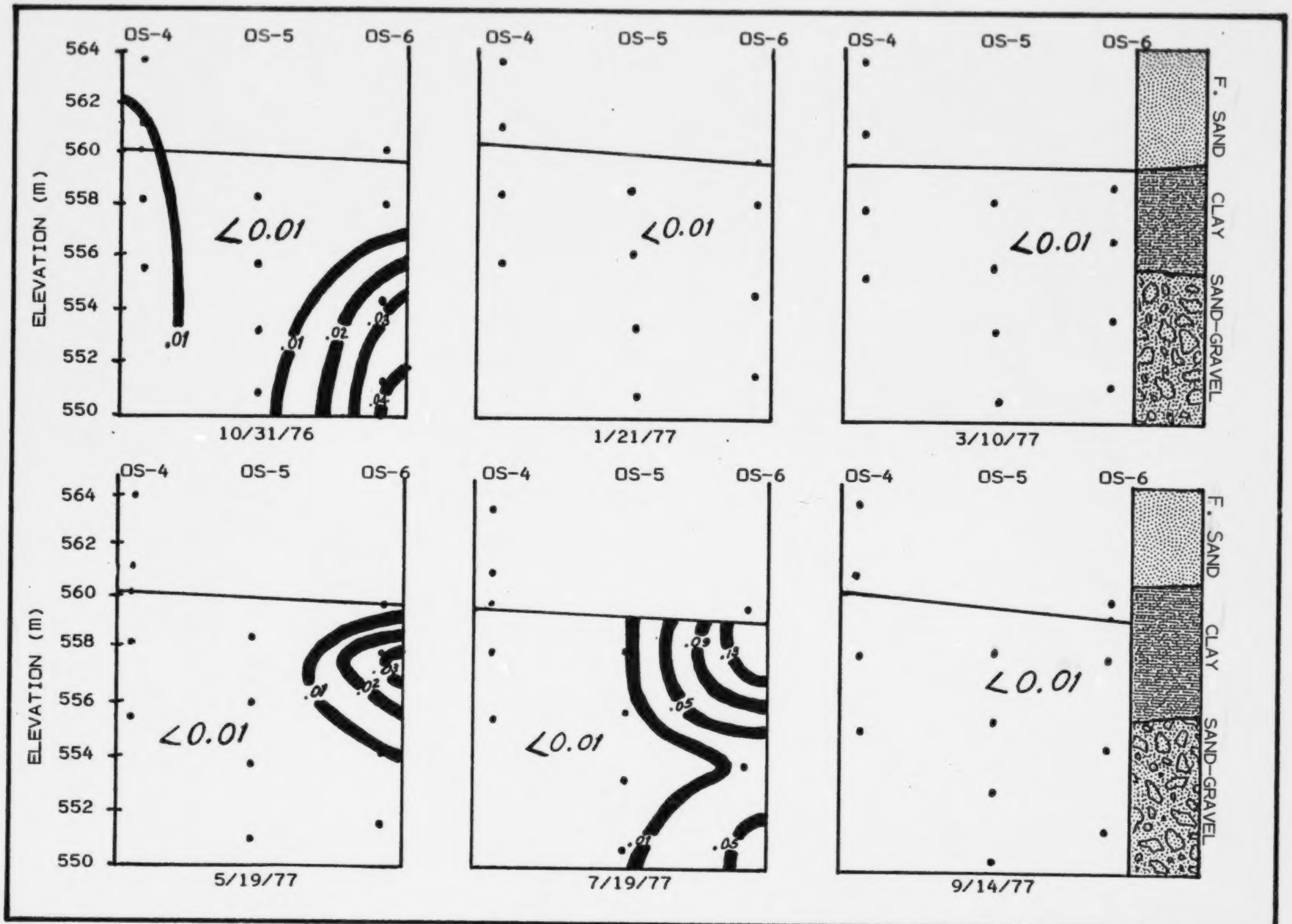


Figure 38a. Site 1 copper concentration isopleths for line 1.

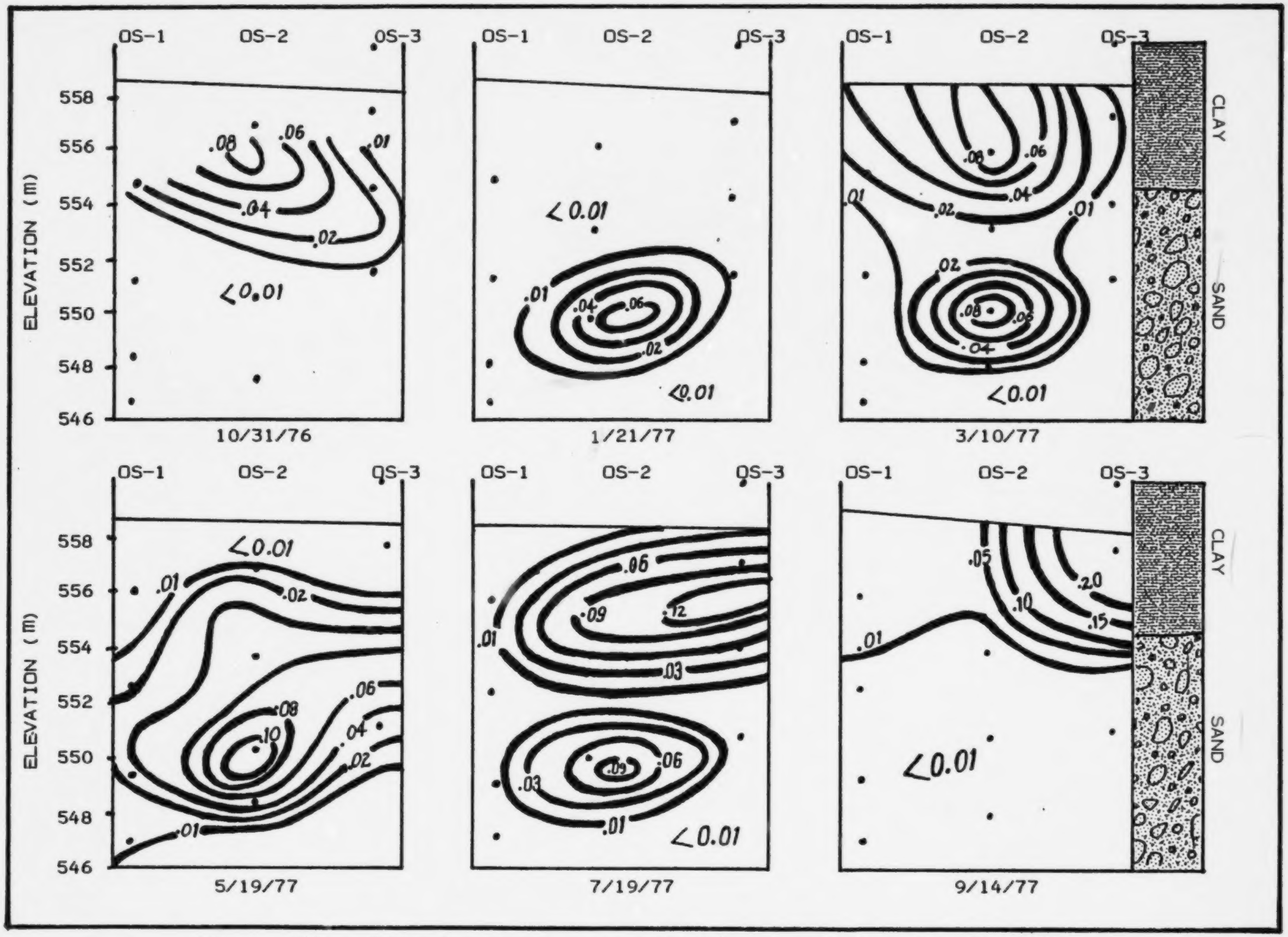


Figure 38b. Site 1 copper concentration isopleths for line 2.

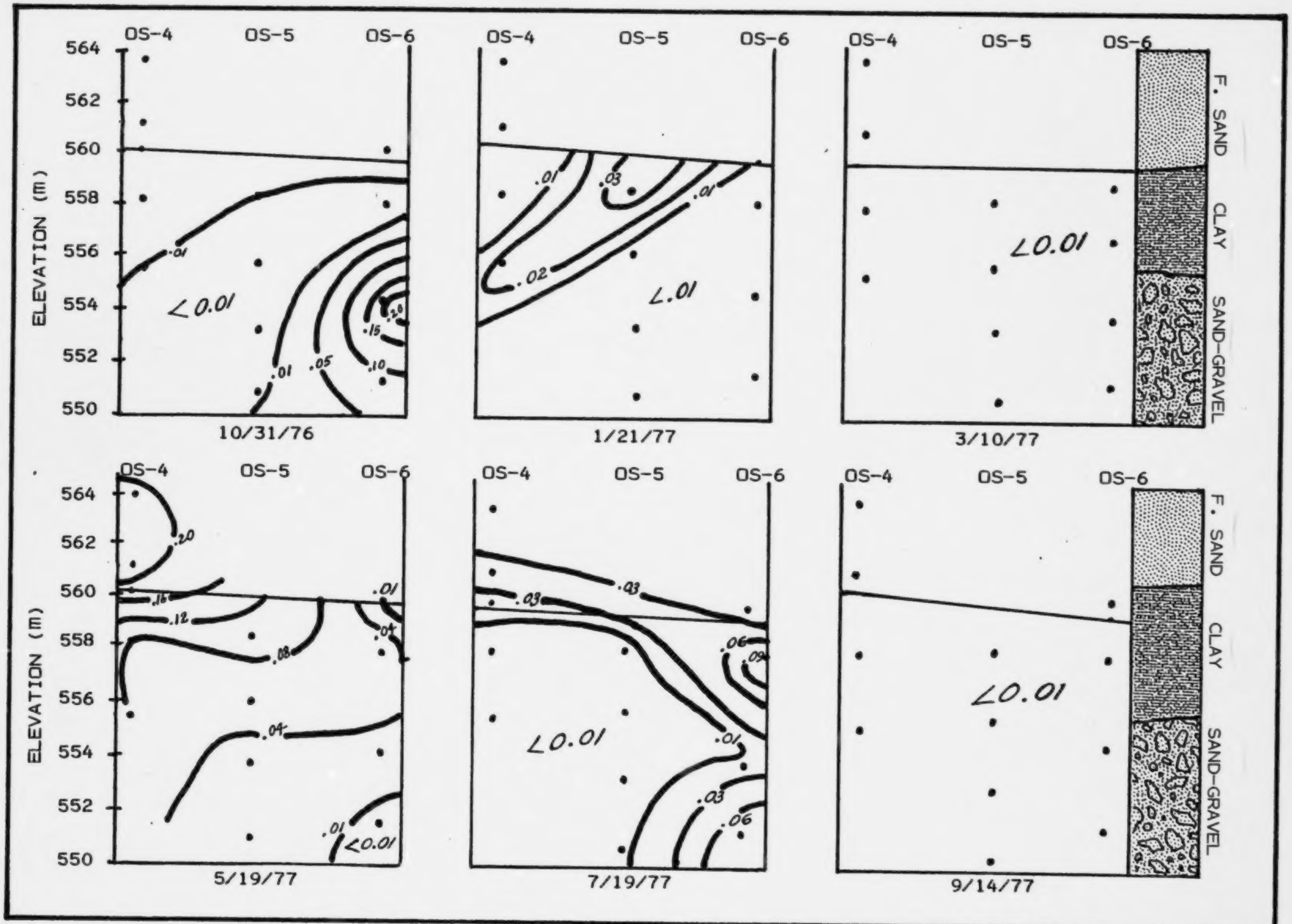


Figure 39a. Site 1 nickel concentration isopleths for line 1.

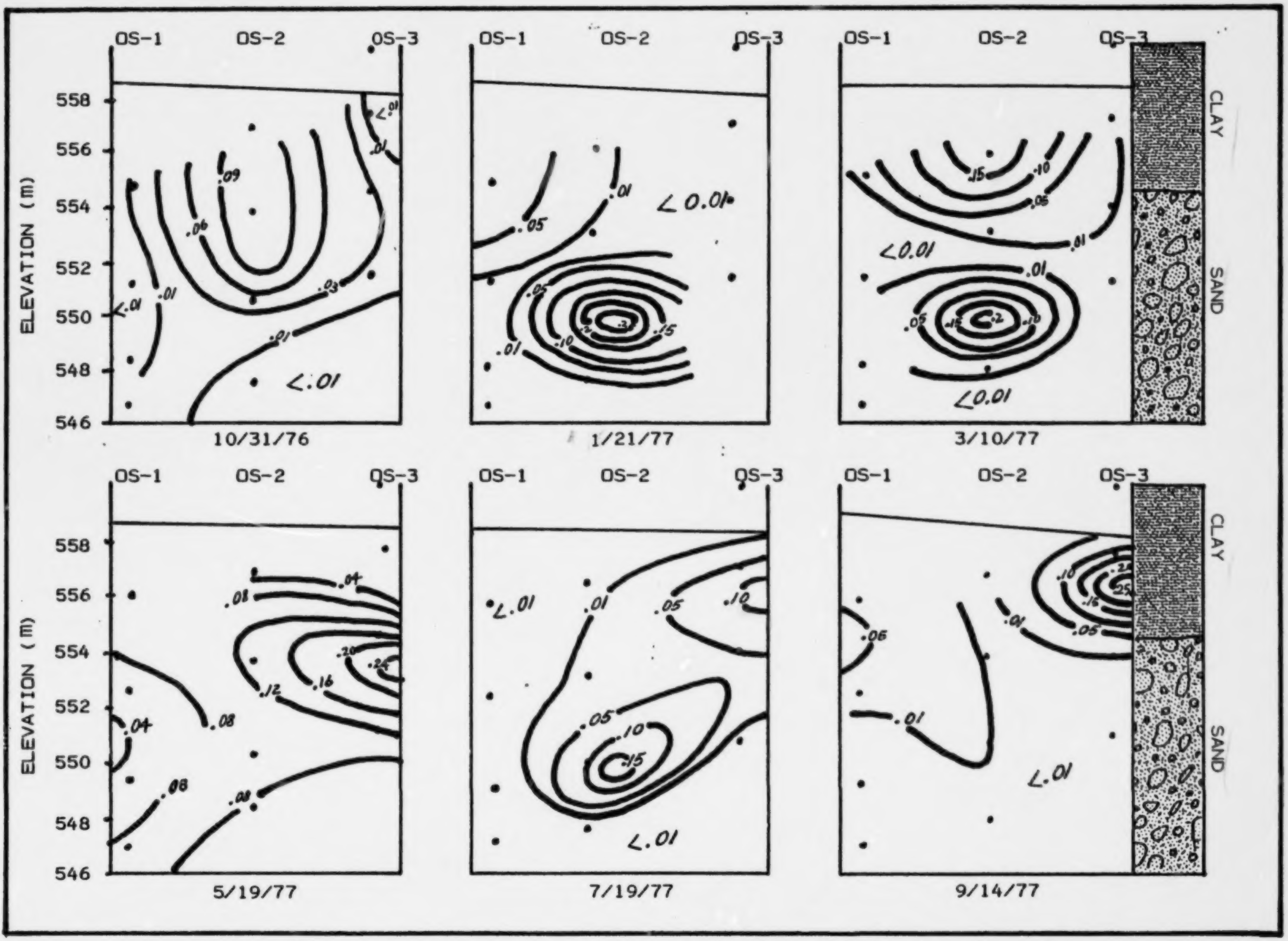
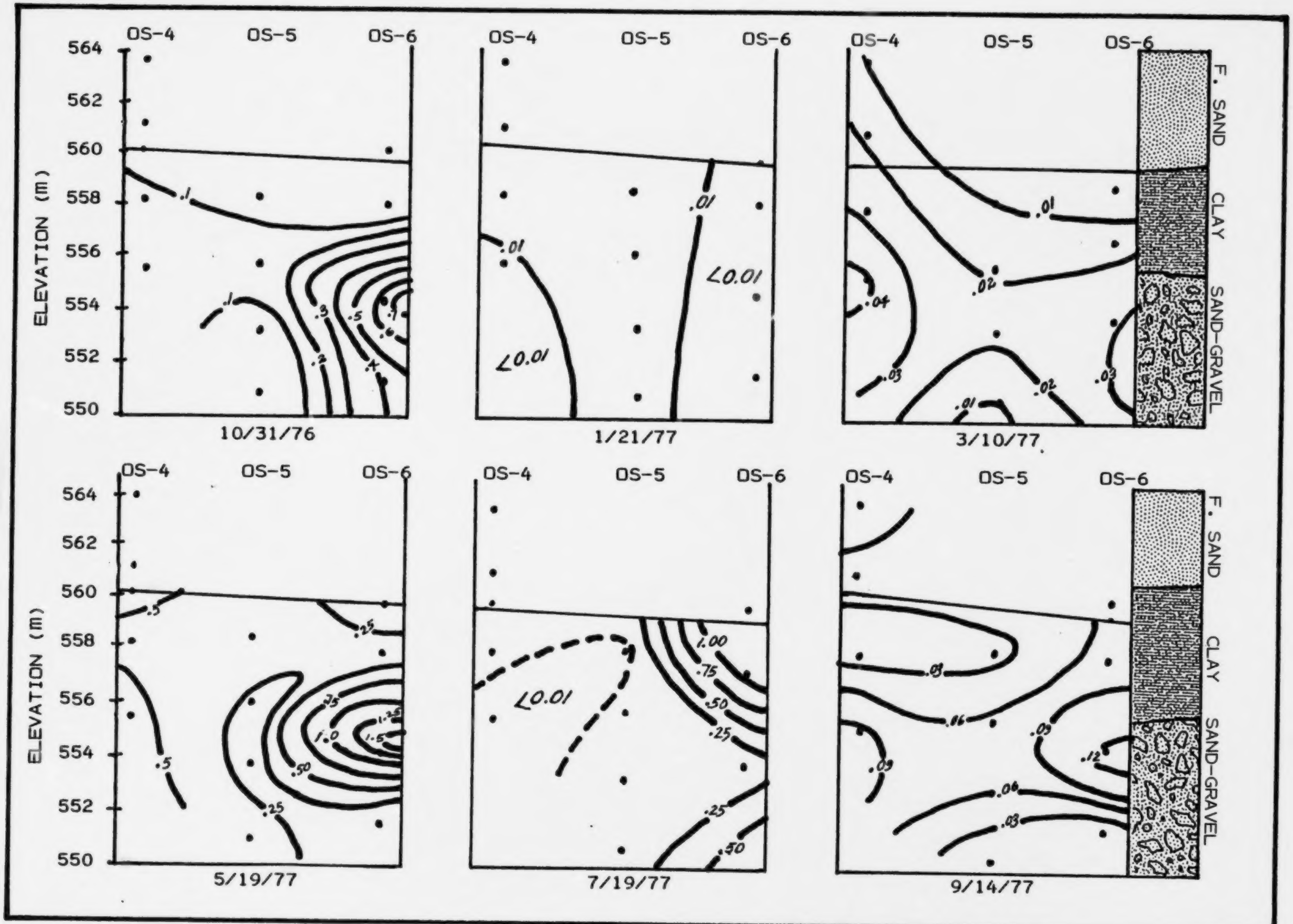


Figure 39b. Site 1 nickel concentration isopleths for line 2.



10/31/76 1/21/77 3/10/77

5/19/77 7/19/77 9/14/77

Figure 40a. Site 1 zinc concentration isopleths for line 1.

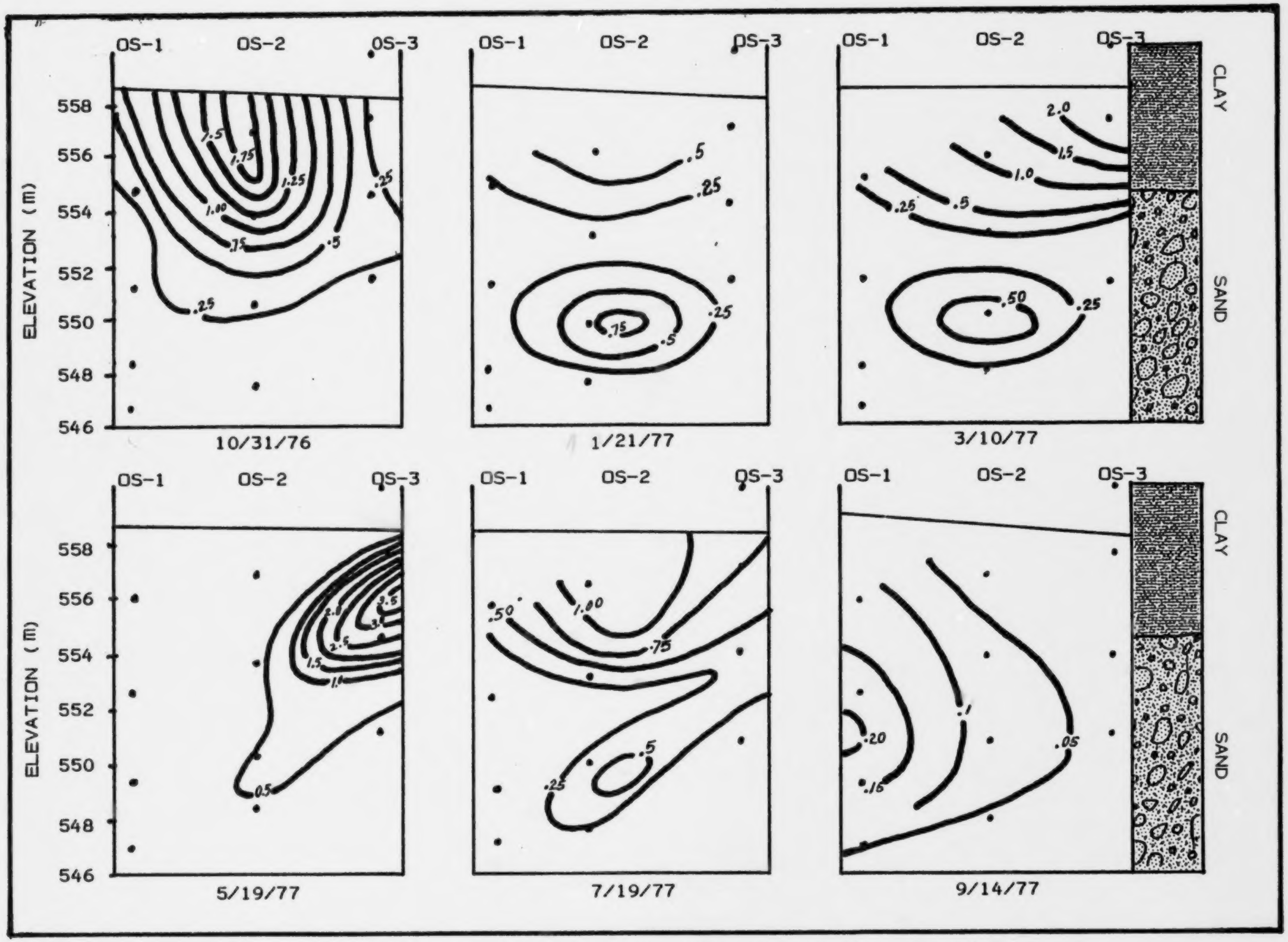


Figure 40b Site 1 zinc concentration isopleths for line 2.

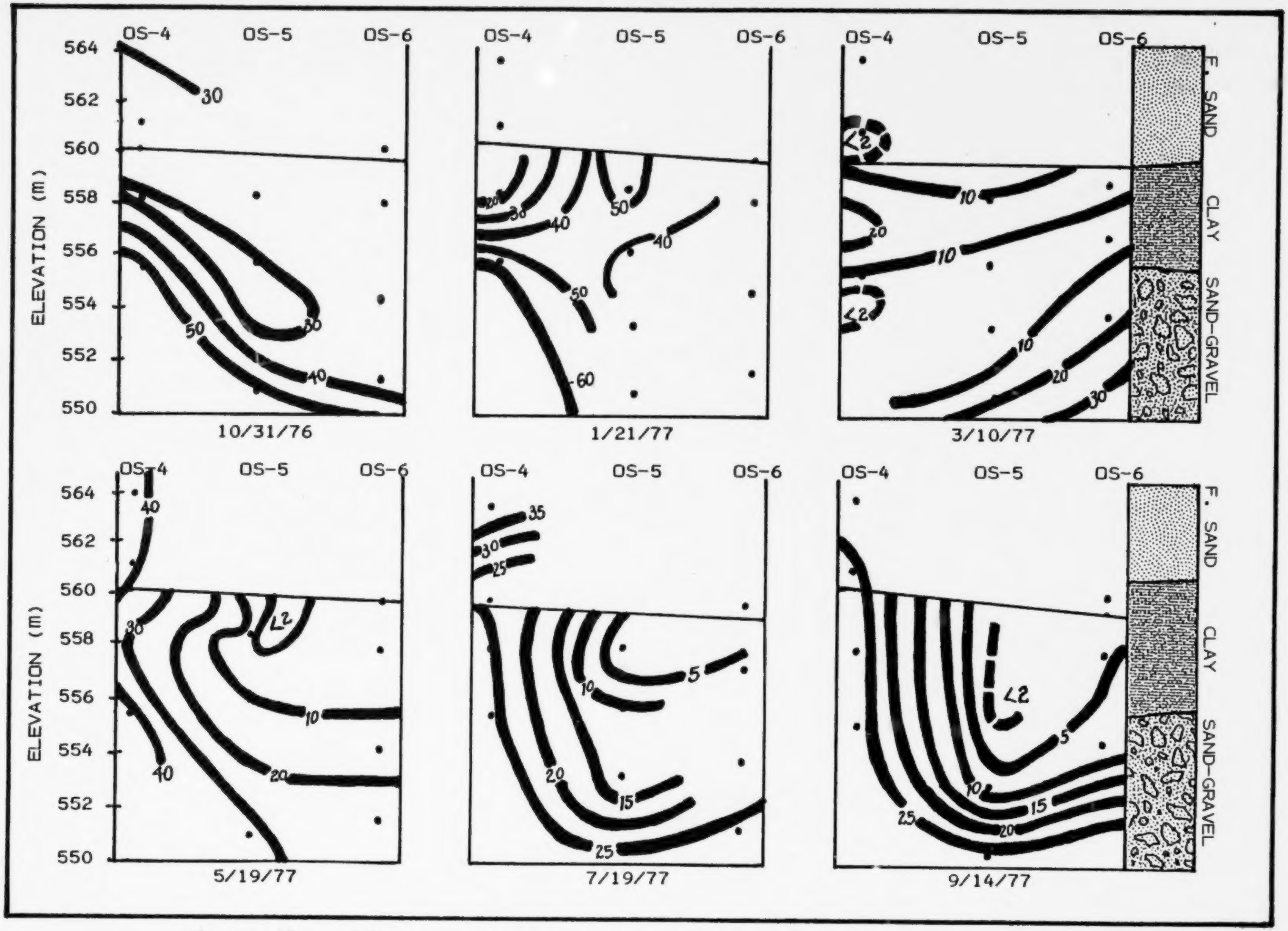


Figure 41a. Site 1 chloride concentration isopleths for line 1.

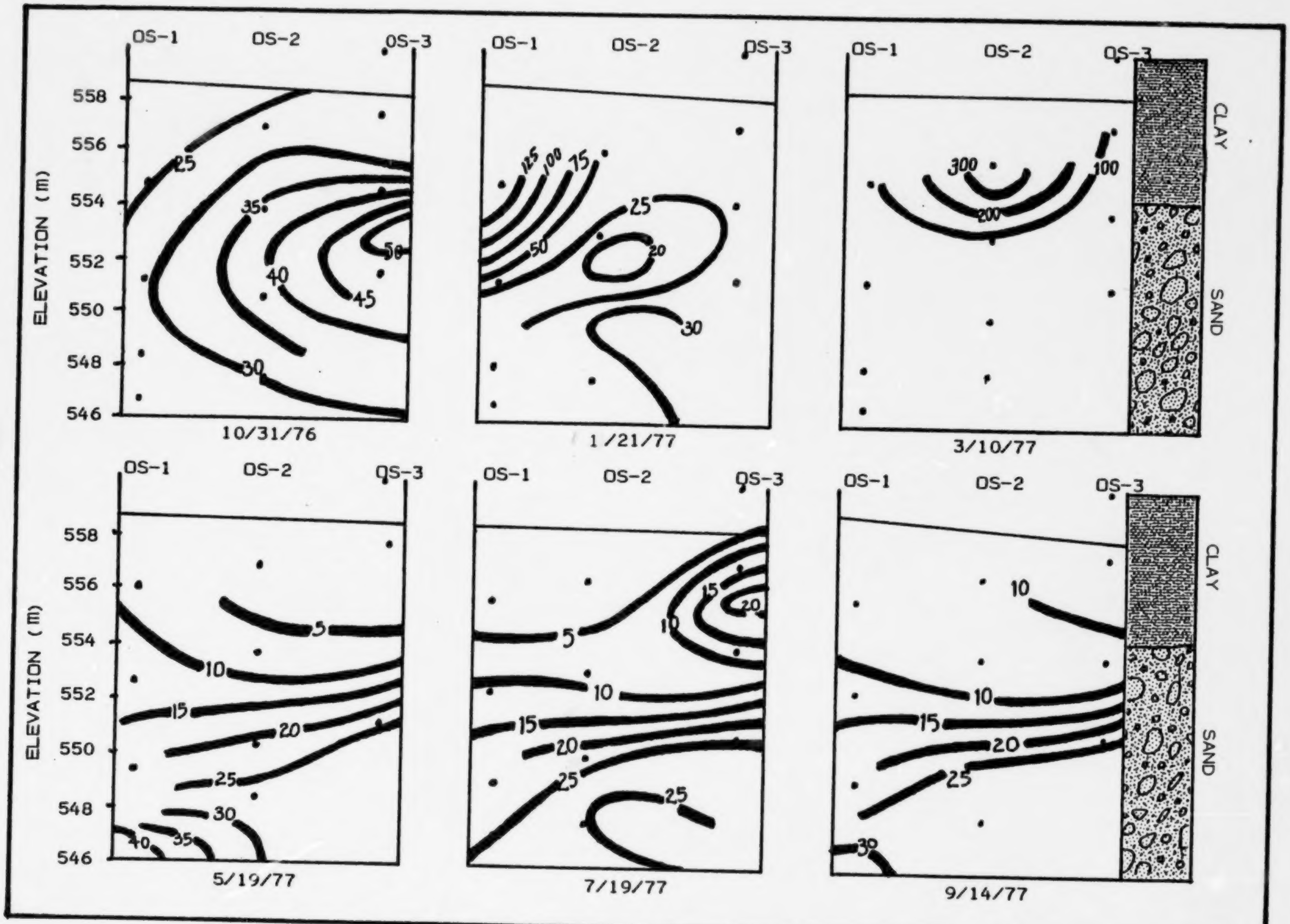


Figure 41b. Site 1 chloride concentration isopleths for line 2.

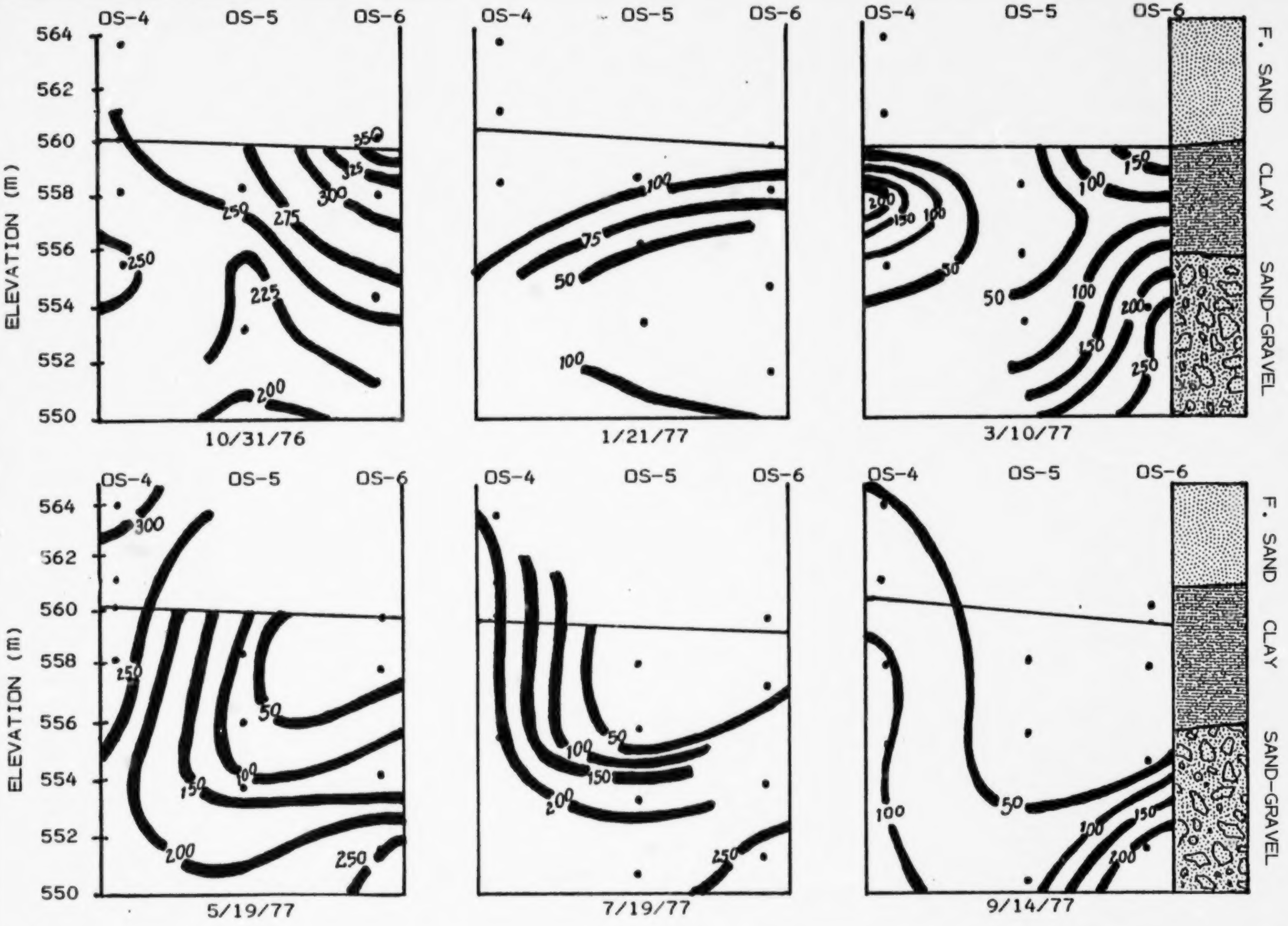


Figure 42a. Site 1 sulfate concentration isopleths for line 1.

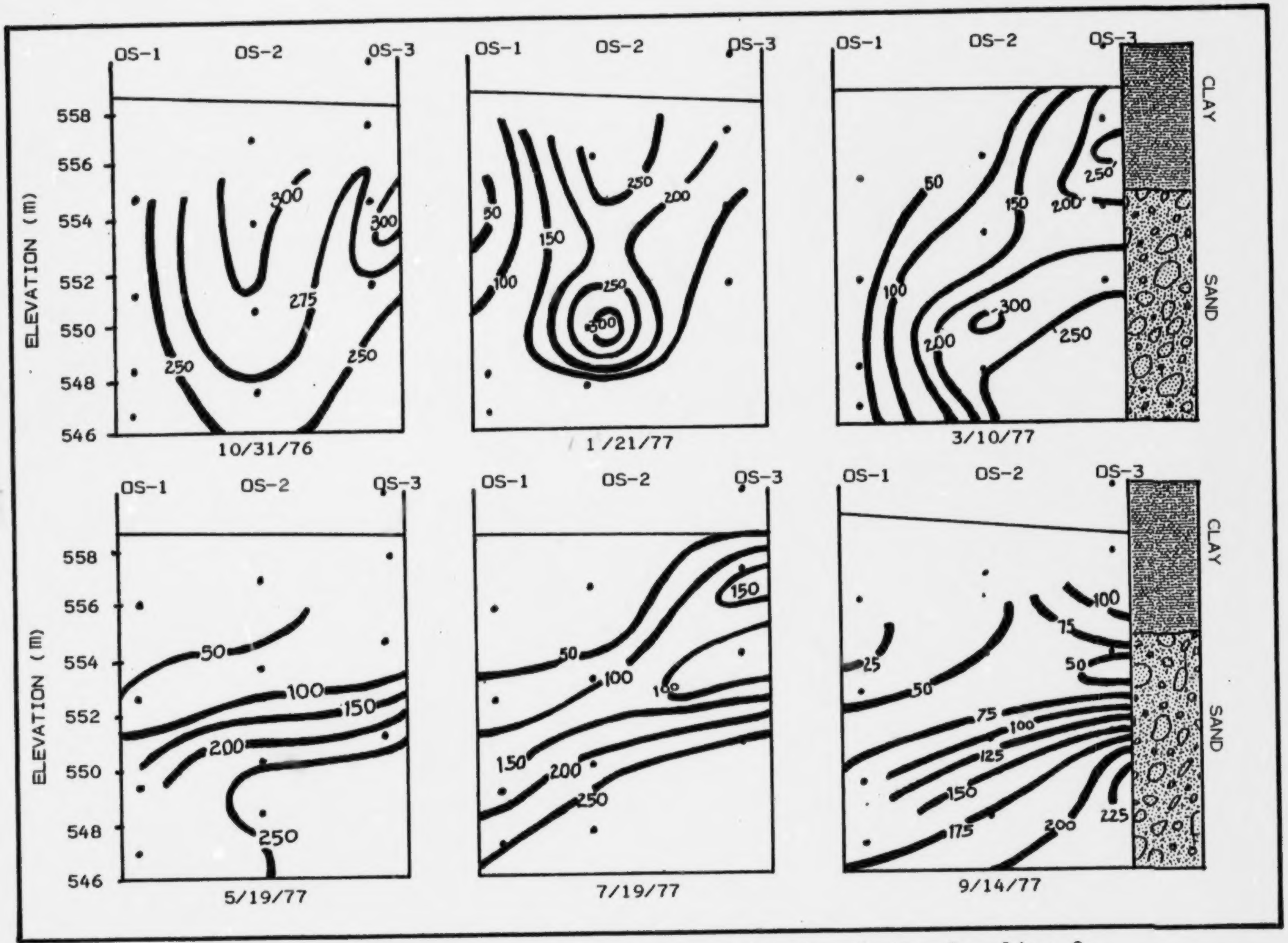


Figure 42b. Site 1 sulfate concentration isopleths for line 2.

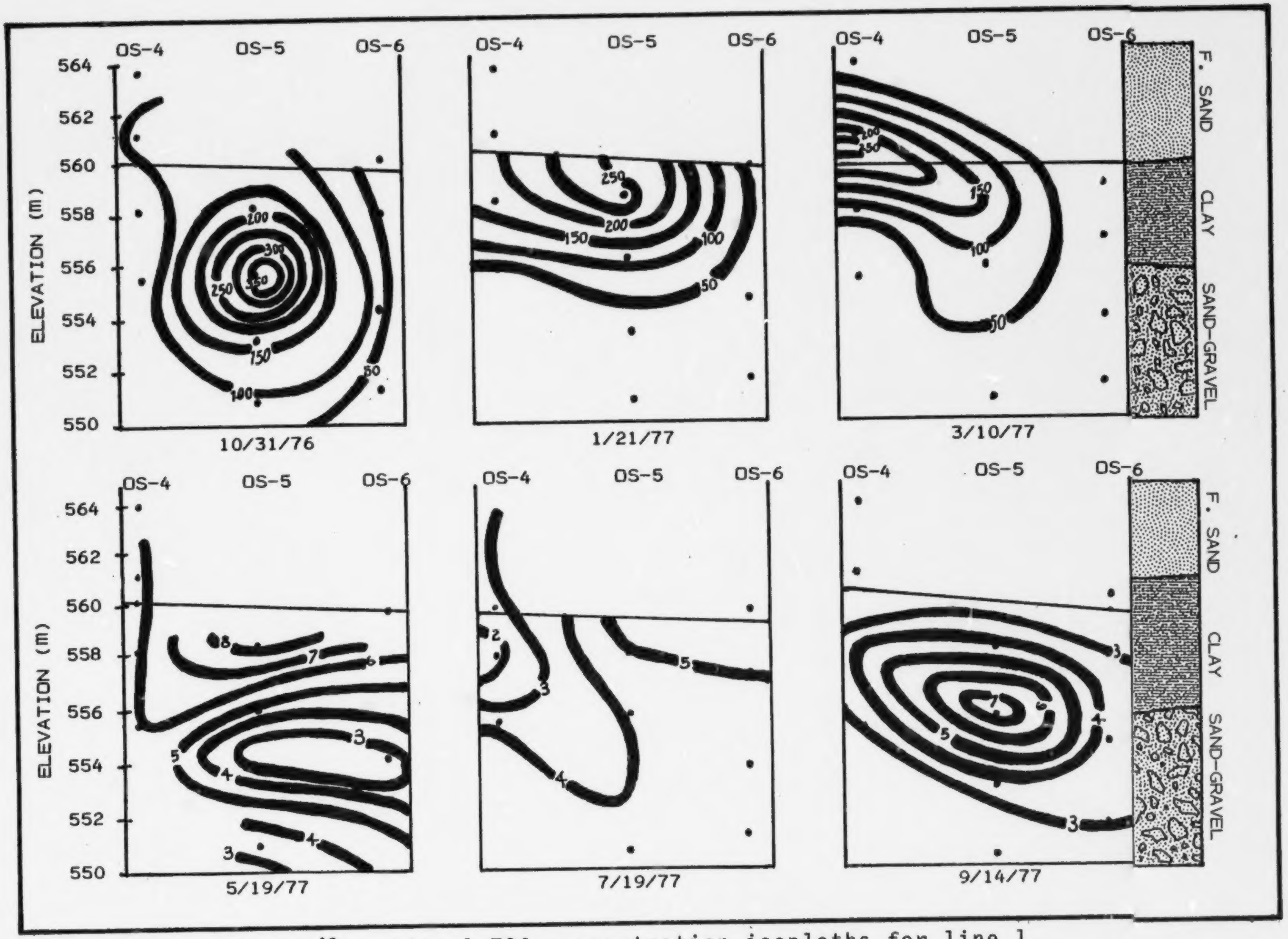


Figure 43a. Site 1 TOC concentration isopleths for line 1.

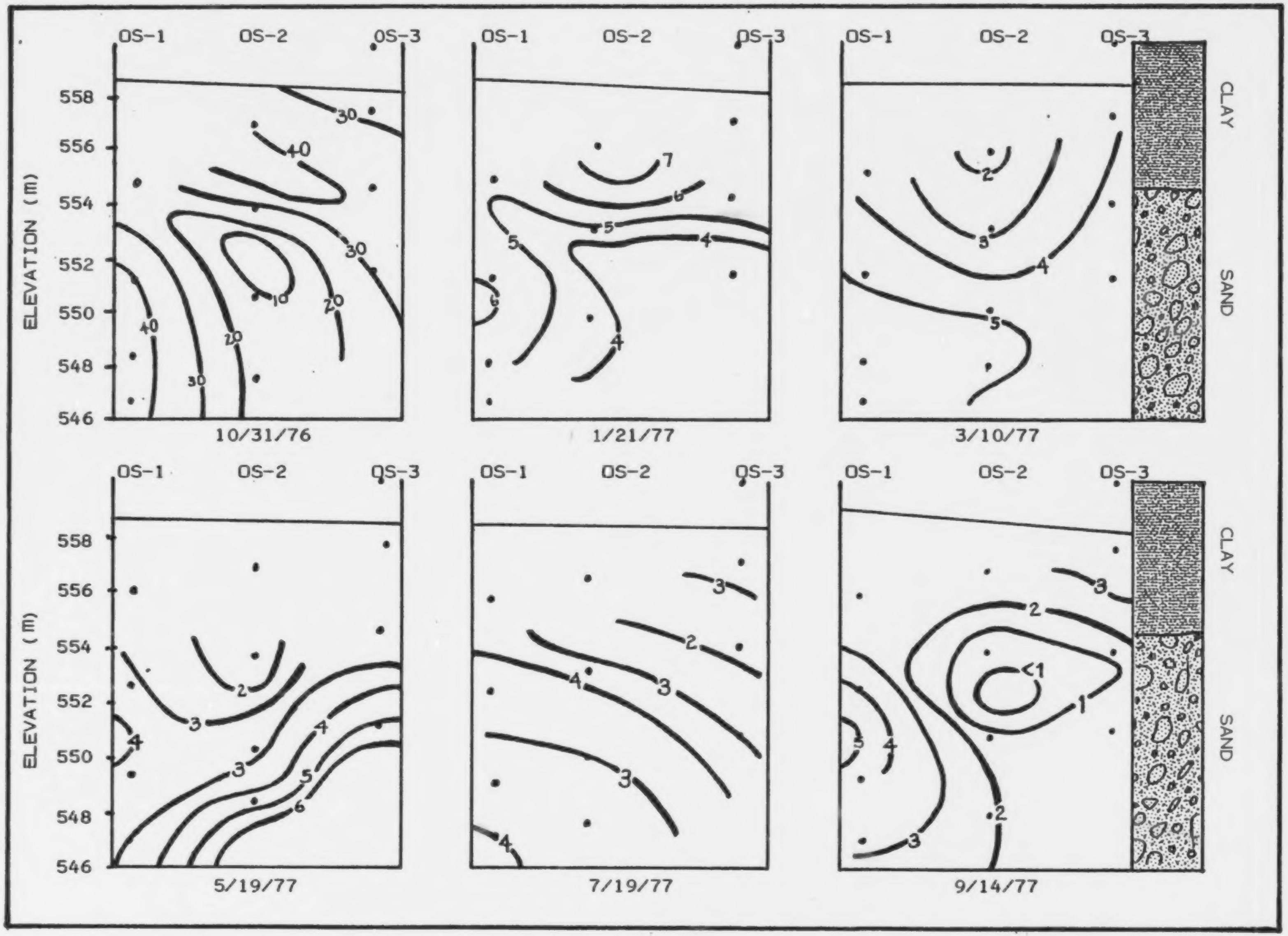


Figure 43b. Site 1 TOC concentration isopleths for line 2.

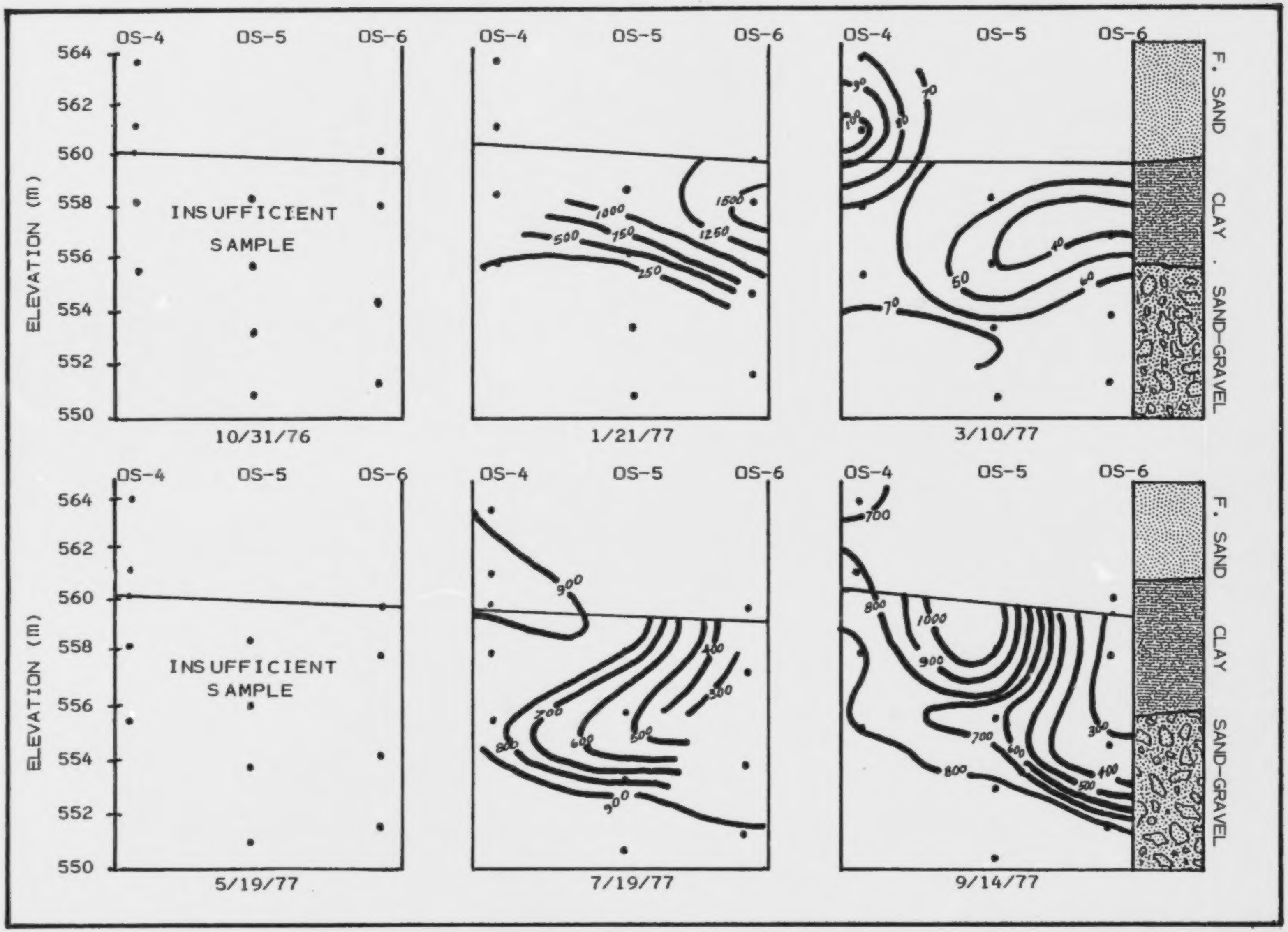


Figure 44a. Site 1 specific conductance isopleths for line 1.

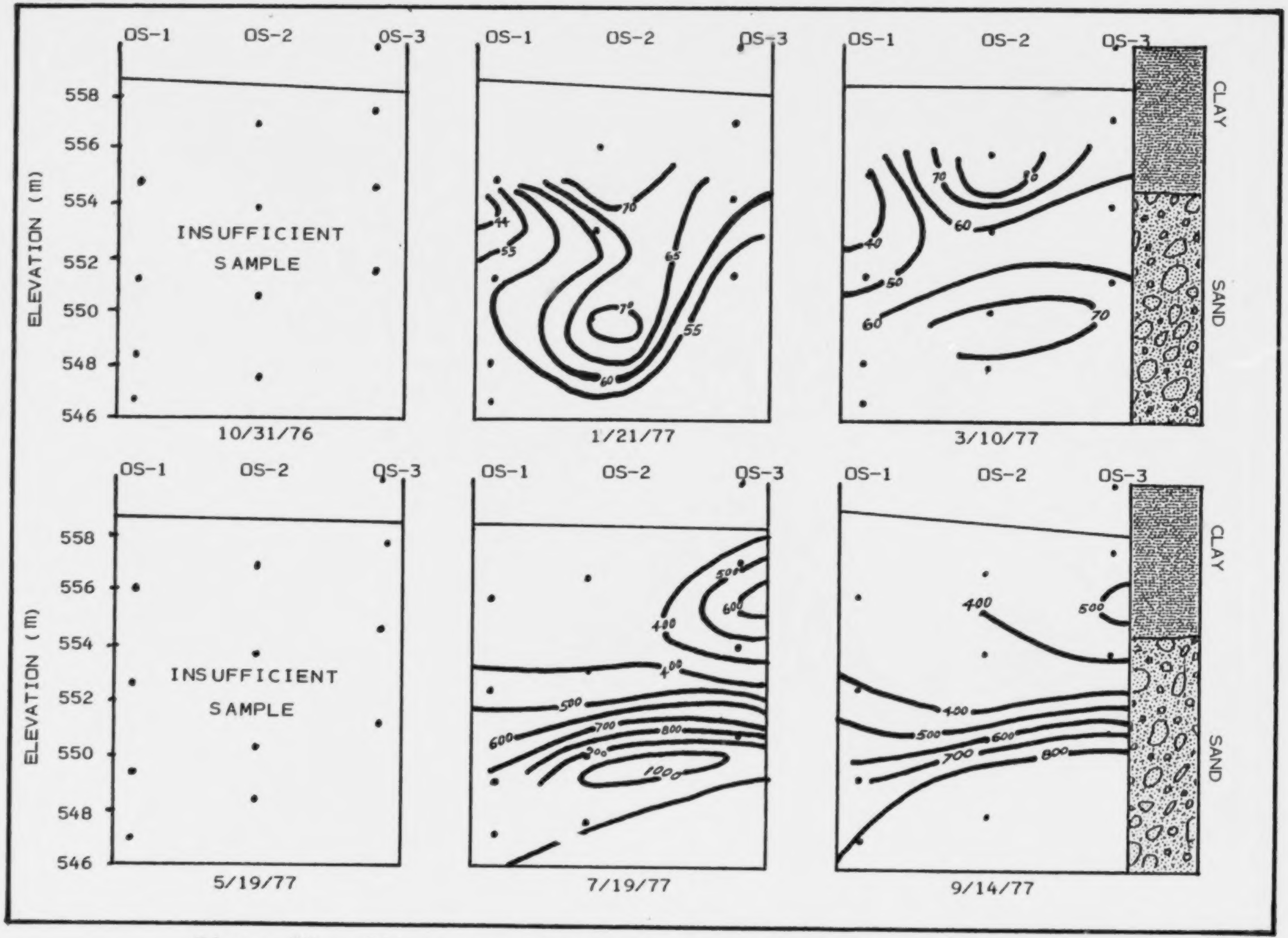


Figure 44b. Site 1 specific conductance isopleths for line 2.

absorbed or precipitated form of low water solubility. Similar fluctuations were noted for iron (Figure 33), indicating shifting in the areas of maximum leachate concentration and the continual dynamic nature of leachate. The presence of more than one concentrated leachate plume was also evidenced by the second, third, and possibly fifth samplings, particularly for cadmium (Figure 36).

Another interesting phenomenon that was demonstrated by more than one of the contaminant concentration isopleths involved the ability of the leachate plume to shift relative positions within the monitored grid. This was best shown by following the progression of the areas of maximum concentration from one monitoring period to another. In the first sampling, the maximum area of concentration was in the upper center of the grid; in the second sampling it was in the lower center of the grid; in the third, it had bifurcated and was of similar concentrations in both upper and lower leachate plumes; in the fourth sampling, it was in a widely distributed lower area of the grid and then reconsolidated itself into a strong, specific, localized concentration plume observed in the fifth sampling. By the sixth sampling, the leachate plume was in the extreme upper right of the grid.

No similarities were observed between the concentration isopleths for either chlorides or TOC and the heavy metals. However, on some occasions, the concentration isopleths for sulfates did have some resemblance to those for certain metals, while on other occasions there were no discernible correlations.

The concentration isopleths for TOC showed that for the first sampling its concentrations were quite high, reaching levels greater than 50 ppm at various locations on the monitoring grid (Figure 43). In the first sampling, it was in a very tight, concentrated, bullseye formation, whereas in the second sampling, it was in the upper horizons of the water table and had shifted slightly by the third sampling. However, in the fourth, fifth, and sixth samplings, the concentrations had been greatly diluted to insignificant levels while maintaining their relative positions. This illustrates the difficulty in determining when and how frequently a landfill must be monitored to obtain useful information for management and/or regulation of the site. Furthermore, as indicated for iron and lead, certain wells exhibited significant concentrations of these contaminants, while other wells did not. Sampling only from the latter wells would have given site operators and regulatory agencies no reason for concern over the quality of groundwater at this site, while the opposite conclusion may actually be more accurate.

The various configurations and locations of the leachate plumes for individual contaminants varied across the face of the monitoring grid at each sampling period. The reason for this may have been the seasonal use of irrigation wells to the south of the landfill, causing seasonal shifts in the direction of groundwater migration. During sample well placement, the groundwater movement was almost due east, with a slight inclination to the southeast. The well placement was designed to catch the presumed mass centroid of leachate emissions. However, the lines of wells should have been wider along the downstream edge of the landfill. There should also have been one or two more wells in each line, and one or two deeper probes placed in the groundwater table. These were indicated by the occurrence of many leachate plumes at the sides and bottom of the monitoring grid.

Environmental Impact Assessment

Leachate was generated and variable amounts escaped over the course of the monitoring year. Less permeable silty sand and clay strata (12.2 to 15.2 m below the groundwater surface) confined the majority of the leachate to the upper level of the groundwater. Monitoring of downstream residential wells located at depths of 32 to 40 m revealed no contamination or adverse impacts on water quality.

Because of the large groundwater recharge due to exfiltration from the river, copious amounts of water were available for dilution and dispersion of leachate-borne contaminants. Nevertheless, during the summer months certain contaminants such as iron, lead, and, on occasion, sulfate and TOC exceeded the drinking water standards in localized places at distances of 61 to 91 m from the downstream edge of the disposal area (Table 17). While certain contaminant concentrations surpassed the drinking standards in the landfill's proximity, it was felt that they would be suitably diluted and dispersed hundreds of meters downstream, assuming there were no significant changes in sludge contaminant levels or in the disposal operation.

It was thought that the silty to sandy clay stratum at about the 12.2-m depth was responsible for controlling the rate of leachate migration into the underlying coarser sand and gravel zone through which much of the river's inland exfiltration occurred. This was the primary line of defense in both attenuating and controlling the rate of heavy metal contaminant flux to this major groundwater aquifer that was used extensively within the surrounding area for residential and agricultural purposes.

Attenuation occurred at this site as evidenced by the heavy metals calculations performed on the control volume. The major concern was for the high iron level that leached in massive amounts from both the landfill and the surrounding soil. Iron concentrations were as high as four orders of magnitude above the EPA drinking water standard. Lead leached in localized "hot spots" from the landfill in the summer.

TABLE 17. NUMBER OF TIMES SAMPLED CONSTITUENT CONCENTRATIONS EXCEEDED EPA DRINKING WATER STANDARDS (SITE 1)

Constituent	Background Wells		Downstream Wells	
	Phase I	Phase II	Phase I	Phase II
Cd	0-2*	0-22	0-3	2-117
Cu	0-2	0-22	0-3	0-125
Fe	0-2	21-22	3-3	101-125
Hg	0-2	2-22	0-3	7-124
Pb	0-2	8-21	1-3	31-117
Zn	0-2	0-22	0-1	3-125
Cl	0-2	0-22	2-3	1-121
SO_4	0-2	5-22	0-3	22-120
TOC	1-2	6-22	2-3	30-120

* The first number indicates number of times standard was exceeded; the second number is sample population.

It was believed to originate predominantly from the landfill rather than from the surrounding soils. Lead concentrations were up to two orders of magnitude above the EPA drinking water standard. Although concentrations of mercury and cadmium in the downstream wells were occasionally above the drinking water standards, there was no indication that the groundwater downstream was contaminated to any degree with these two metals to be of concern. Concentrations of TOC were high initially, but decreased to less than 5 ppm later in the monitoring period.

A much more detailed and thorough evaluation of metal migration might be obtained through thermodynamic calculations based on metal speciation using selected parameters as indicators. The parameters are:

- Dissolved oxygen
- Sulfides
- Chlorides
- Sulfates
- Carbonates
- Soluble organic species (e.g., fulvic and humic acids)
- pH
- Eh
- Ammonia.

The above parameters would allow us to predict the maximum upper concentrations of a particular species, the metal species, and to calculate attenuation and elution. Based on these calculations, it is possible to predict the distance the contaminants would migrate in characterized porous media.

In summation, while leachate contamination of the upper groundwater zone occurred in measurable amounts, it was expected that dilution and attenuation would mitigate these results within hundreds of meters from the landfill. The groundwater quality at lower depths did not appear to be adversely affected due to controlled rate of flux through the silty clay layer and subsequent dilution.

SITE 2

Soil Analyses

During the drilling of the in-refuse well, soil samples were taken at the refuse-soil interface (9.1 to 9.4 m) and soil groundwater interface (10.7 m). Results of the sequential extraction with water and concentrated nitric acid are presented in Table 18.

The soils in the disposal area were fine-textured, saline (containing high levels of soluble salts), and strongly alkaline (pH 8.2). Concentrations of the selected chemical constituents in the water, as well as acid extracts, were generally low and showed little variation with soil depth. The concentrations of heavy metals were less than those commonly found in soils (1, 2). The relatively high concentrations of water-soluble iron at the two soil depths suggested a reducing regime.

Sludge Analyses

Two grab sludge samples, one obtained from material excavated during placement of the in-refuse well (June 1975) and the other from the sewage treatment plant (June 1976), were sequentially extracted, first with water and then with concentrated nitric acid (Table 15). Since the moisture content was not determined for the 1975 sample, no comparison could be made of the differences in sewage sludge composition between 1971 (burial date) and 1976.

Results of the sludge obtained from the fill materials showed high concentrations of sulfate and soluble calcium; some of the soluble salts in this sludge may have been leached out. The metal concentrations were within the range but less than the median concentrations reported by Sommers (9). Due to the alkalinity of the soil in and around the fill, the movement of heavy metals away from the fill should be minimal. On the other hand, the high soluble salt content (as indicated by chloride and sulfate concentrations in the soil and leachate) might reduce the capacity of the soil to retain these metal contaminants.

Leachate Analyses

The leachates collected from the in-refuse well during Phases I and II were analyzed for selected chemical constituents (Table 19). For the four sampling dates in Phase I, concentrations of total solids, TOC, COD, TKN, ammonium, chloride, sulfate, iron, and lead were highest in the first sampling. This might be due, in part, to disturbances to the fill during the installation of the well. Concentrations of various constituents generally decreased in subsequent samplings, a probable result of rainfall that diluted the leachate. Among the heavy metals,

TABLE 18. ANALYTICAL RESULTS FOR SITE 2, PHASE I*

	Soil Samples Taken Below Landfill During Drilling of In-Refuse Well			
	Refuse-Soil Interface (9.1 to 9.4 m)		Soil-Groundwater Interface (10.7 m)	
Constituent†	Water	Acid	Water	Acid
	6/17/75		6/17/75	
pH	8.2		8.1	
TOC	315		275	
COD	723		712	
TKN	124		103	
NH_4-N	11.1		7.7	
NO_3-N	<0.4		0.5	
Cl	72		89	
SO_4	170		191	
Ca	6	1142	51	1307
Cd	<0.03	0.09	<0.03	0.51
Cr	<0.30	2.39	<0.30	2.57
Cu	<0.20	3.00	<0.20	12.30
Fe	4.20	3250	9.90	3513
Hg	0.005	0.010	≤0.001	0.007
Pb	0.4	8.1	0.6	6.5
Moisture, %	23.4		24.1	

Refuse percent moisture (2.4 m) 22.1
(2.7 m) 29.0
(5.2 m) 36.0
(6.1 m) 41.0

TABLE 18. (continued)

	Sludge#				Background Groundwater	
	Water	Acid	Water	Acid		
Constituent†	6/17/75		6/4/76		9/18/75	6/4/76
pH					8.2	
Tot. Solids					4029	
TOC	8250		42742		54	14
COD	31416				82	
MBAS			<0.1			0.15
TKN	608				2.4	
NH_4-N	122				1.6	
NO_3-N	2.4				<0.02	
Cl	256		10		1201	1500
SO_4	5450		38		375	360
Ca	19625	1775			76	
Cd	<0.03	0.66		3.6	0.014	0.001
Cr	<0.30	7.00		22	<0.01	<.01
Cu	<0.20	11.90		62	0.043	<.01
Fe	0.56	4933		1000	0.86	2.5
Hg	0.680			<0.003	0.0016	<0.0002
Ni				9.6		.01
Pb	1.2	48		55	0.040	.02
Zn				150		2.1

TABLE 18. (continued)

	Offsite Well (Shallow)			Offsite Well (Deep)			
Constituent[†]	7/8/75		6/4/76	7/8/75	9/18/75	10/14/75	6/4/76
pH	7.6	Insufficient sample on 9/18/75 and 10/14/75 for analysis		7.7	7.9	7.6	
Tot. Solids	22548			29299	6887	2006	
TOC	700		14	350	32	68	9.2
COD	2746			1581	54	83	
MBAS			<0.01				<0.01
TKN	36			14.2	2.1	1.3	
NH_4-N	4.5			2.5	0.6	1.1	
NO_3-N	0.10			0.05	0.32	0.30	
Cl	234		132	687	273	360	580
SO_4	135		60	210	238	108	170
Ca	25			30	53	23	
Cd	0.015		0.002	0.030	0.009	0.004	0.003
Cr	0.65		< 0.01	0.98	0.02	0.02	0.02
Cu	0.330		0.01	0.540	0.008	0.009	<0.01
Fe	540		2.3	1090	0.42	0.23	0.44
Hg	0.003		< 0.0002	0.006	0.0003	0.0002	0.0002
Ni			< 0.01				<0.01
Pb	0.740		0.02	1.890	0.056	0.070	0.58
Zn			0.03				0.08

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* Soil and sludge were extracted with water and concentrated nitric acid. Sampling dates are also indicated.

† Concentrations are expressed as mg/kg of dry soil, mg/kg of wet sludge, mg/l of groundwater or leachate.

# Moisture content for the 6/4/76 sample was 86 percent.

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TABLE 19. CHEMICAL ANALYSIS OF LEACHATES FROM IN-REFUSE WELL (SITE 2)

Constituent*	Phase I			
	7/8/75	9/18/75	10/14/75	6/4/76
pH	6.9	7.8	7.9	
Tot. Solids	12465	5940	5433	452
TOC	2750	1067	1350	
COD	5637	2687	2000	
MBAS				<0.01
TKN	161	103.7	80	
NH_4-N	130	70	57	
NO_3-N	<0.02	0.02	0.02	
Cl	29	350	492	70
SO_4	1600	76	1	540
Ca	510	161	77	
Cd	0.009	0.025	0.011	0.003
Cr	0.14	0.01	0.47	0.01
Cu	0.100	0.02	0.015	<0.01
Fe	64	2.76	0.75	1.5
Hg	0.007	0.033	0.0005	<0.0002
Ni				0.08
Pb	0.310	0.200	0.263	0.10
Zn				0.01

TABLE 19. (Continued)

Constituent*	Phase II†				
	11/1/76	1/21/77	5/18/77	7/18/77	9/13/77
Cd	0.005	0.010	0.005	<0.005	0.020
Cr	0.03	0.04	0.04	0.02	0.03
Cu	0.03	0.03	<0.01	<0.01	0.03
Fe	5.50	1.90	1.20	1.50	1.70
Hg	<0.0002	<0.0002	<0.0002	0.0002	0.0003
Ni	0.16		0.20	0.12	0.09
Pb	1.400	0.150	0.240	0.440	0.370
Zn	0.32	1.40	0.18	0.06	0.20
Cl	61	70	4	576	4
SO_4	950	1250	1290	1400	723
TOC	520	451	346	318	148
Sp. Cond.	--#	850	--	7500	4400

*Specific conductance in µmhos/cm, all other constituents concentrations in ppm.

†No sample taken on 3/10/77 due to dry well.

#Insufficient sample.

lead was present at relatively high levels (average of 0.22 ppm). Fluctuations in constituent concentrations are probably related to the volume of leachate from periods of dry and wet weather.

In Phase II, concentrations of TOC, chloride, and mercury decreased considerably, while sulfate, zinc, and lead increased. Concentrations of sulfate (average of 1,123 ppm) and lead (average of 0.52 ppm) reflected the highly contaminated nature of the fill leachate. Because the lower portion of much of the landfill lay below the water table, this leachate will mingle with groundwater.

Gas Composition in the In-Refuse Well

Gas samples collected at two different depths from the in-refuse well were analyzed for methane, carbon dioxide, oxygen, and nitrogen (Table 20). The oxygen and nitrogen contents in the September samples approached atmospheric values of these two gases, indicating contamination during sampling. The October sample showed methane and carbon dioxide to be the major gases at both depths. The sample at the lower depth showed an increase in methane and a significant decrease in oxygen and nitrogen, thereby bearing out the general observation that the more active methane generation occurs at lower depths in a landfill.

Groundwater Analyses

Two grab samples of background water from a private well and four groundwater samples from the shallow (OS-1 at 3.0 m) and deep (OS-2 at 10.4 m) off-site wells were obtained during Phase I. Bimonthly samples were taken from the two off-site wells and also from the background well (BG at 5.8 m) in the Phase II monitoring. Results of Phases I and II are presented in Table 18 and in Table 2 of Appendix E, respectively.

Background Groundwater--

The first grab sample of background groundwater was strongly alkaline (pH 8.2) and contained relatively high concentrations of total solids, TOC, and COD, and exceedingly high levels of chloride (1,201 ppm) and sulfate (375 ppm) (Table 18). The sulfate and chloride levels were confirmed by the second grab sample taken 9 mo later. Among the heavy metals, iron, lead, and zinc concentrations were slightly elevated. Overall, the data indicated that the quality of this background groundwater was poor.

The groundwater collected from the project background well during Phase II monitoring showed considerably lower levels of sulfate, chloride, and zinc when compared to the background groundwater data from Phase I. It is believed that the wells upstream from the landfill were contaminated with sulfate and chlorine from the connate brines originating from the Dakota

TABLE 20. GAS COMPOSITION AT SITE 2 IN-REFUSE WELL

Gas Species	7/8/75 Upper	7/8/75 Lower	9/8/75 Upper	9/8/75 Lower	10/14/75 Upper	10/14/75 Lower
	%					
CH_4	--*	--*	4.3	2.8	39.5	49.9
CO_2	--	--	1.1	1.7	37.1	37.3
O_2	--	--	20.0	20.4	5.2	2.3
N_2	--	--	77.6	75.1	23.0	10.5

*Buret broken in transit.

sandstone. In the background well installed in Phase II, iron, lead, and zinc concentrations were again slightly elevated. The sources of these metals were not known, but probably originated from the background soil and connate brines rather than the landfill, since their levels and those of sulfate, chloride, and TOC (Phase II) in the background groundwqter generally were lower than the corresponding levels in the downstream groundwater (Figures 45 and 46).

Downstream Groundwater--

Data from the first Phase I sampling suggest possible contamination by suspended colloidal particles (organics, silt, and clay) in the water samples, as evidenced by the extraordinary high levels of total solids, TOC, COD, and iron. It appeared from the July 1975 samples that the deep off-site well intercepted groundwater containing higher concentrations of sulfate, chloride, and heavy metals than did the shallow off-site well. However, the opposite trend was observed in the June 1976 samples.

Fluctuations in contaminant concentrations over the sampling dates were noted in Phase I (Table 18). In the deep off-site well, chloride, sulfate, and lead were present at consistently high levels, while iron was surprisingly present in relatively low concentrations (0.23 to 0.44 ppm) excluding the June 1975 sample. The data presented clearly indicated the contamination of the groundwater by chloride, sulfate, and lead in the deep off-site well.

The shallow off-site well was dry during the Phase II monitoring, so no sample was obtained. Phase II data showed an increase in the concentrations of iron, mercury, lead, and zinc and a decrease in chloride in the off-site deep groundwater. Fluctuations in contaminant concentrations were also observed (Figures 45 and 46). The increases in heavy metal concentrations can partially be attributed to the concentrating effect by dry weather. Although inconclusive, data suggested that the poor quality of the off-site deep groundwater was the result of landfilling.

Environmental Impact Assessment

Groundwater quality in the area is dependent on the proximith to Dakota sandstone bedrock. In many areas the groundwater from this aquifer is highly mineralized. Over-pumping of some local wells has caused intrusion of salt water into the alluvium in some areas.

Local residents have complained about the poor quality of the groundwater supply. To determine the possible degradation of groundwater quality at this site, concentrations of selected contaminants were compared with EPA drinking water standards (Table 21).

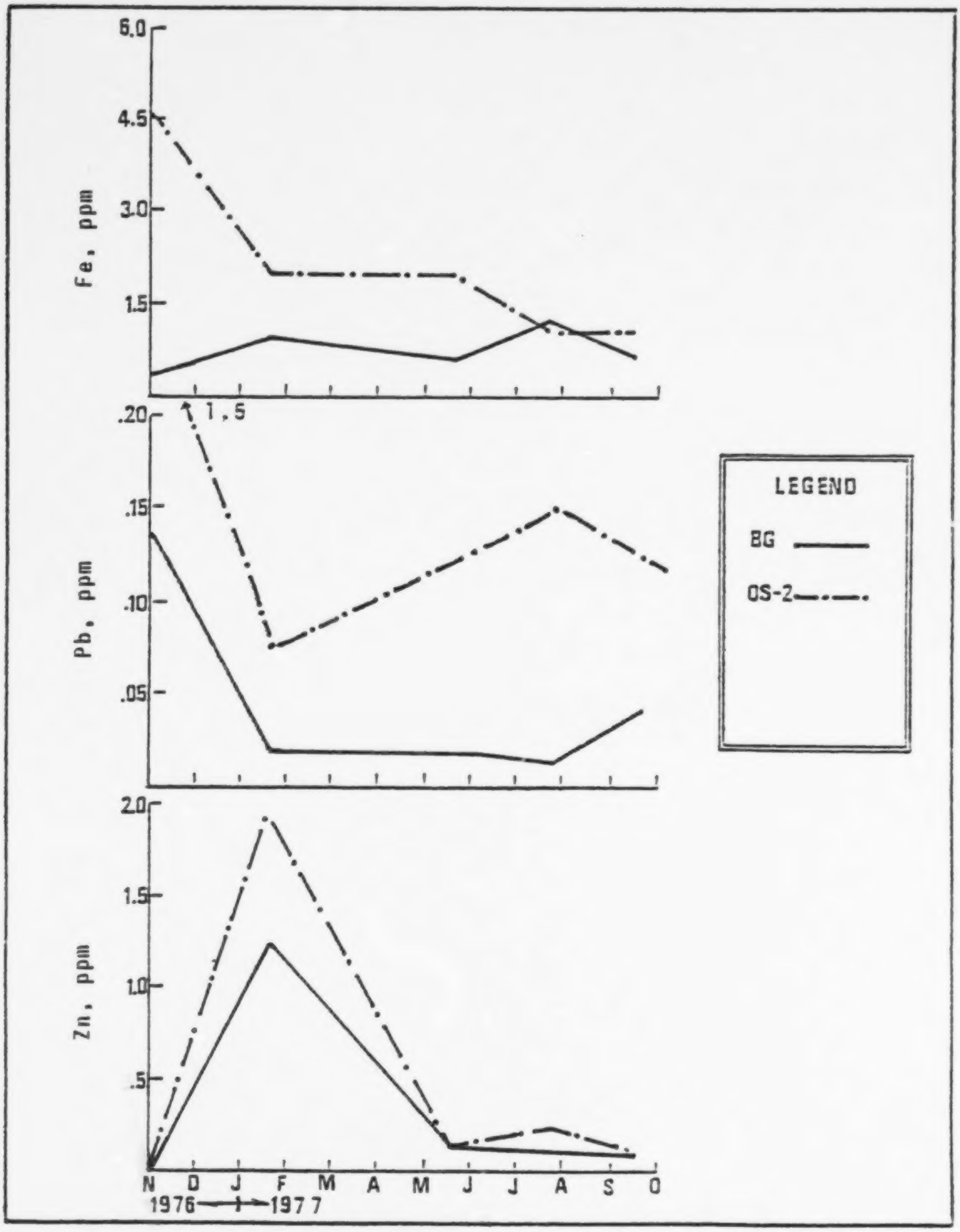

Figure 45. Fe, Pb, and Zn levels in groundwater. (Site 2)

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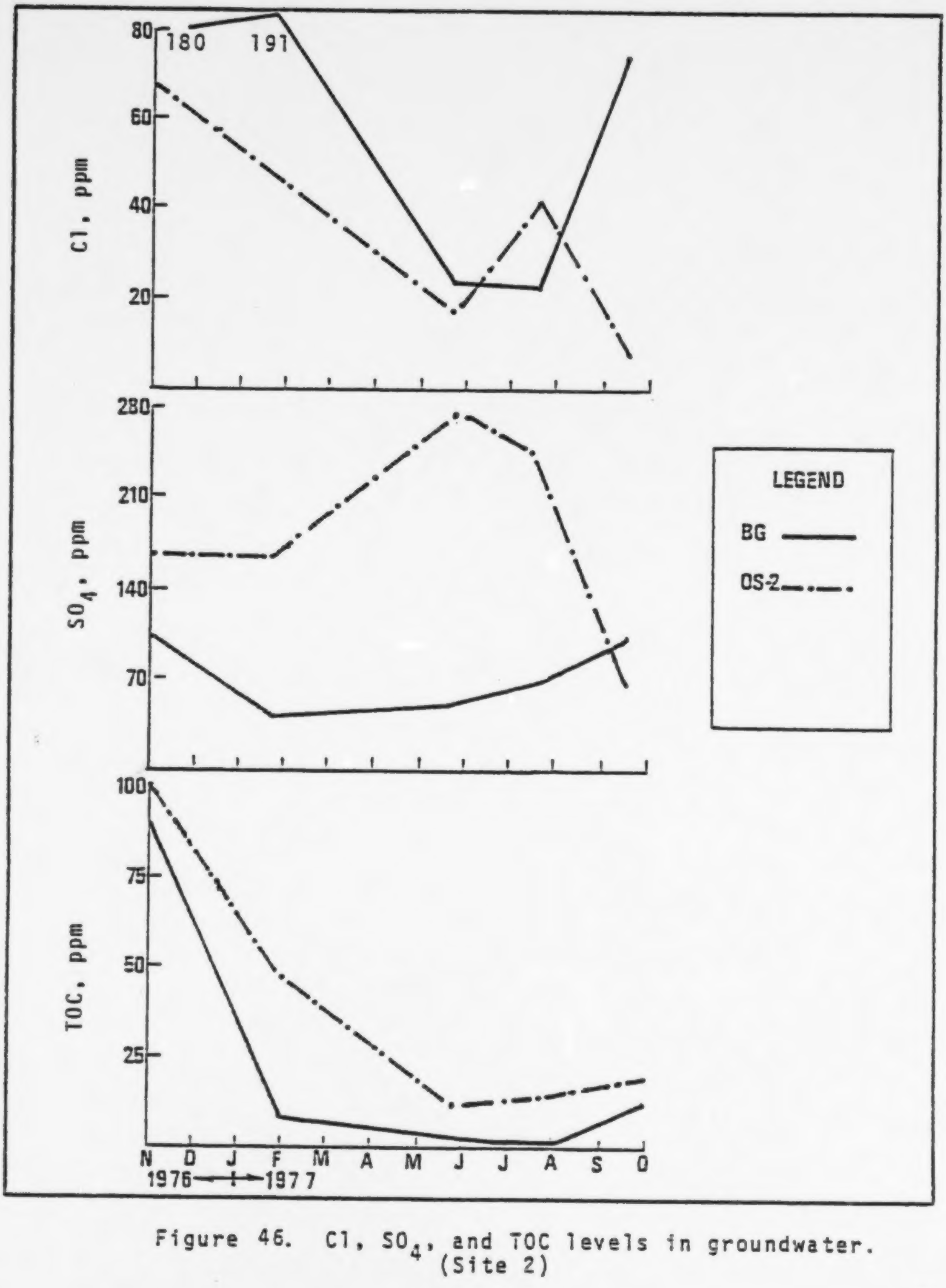

Figure 46. Cl, SO_4, and TOC levels in groundwater. (Site 2)

TABLE 21. NUMBER OF TIMES SAMPLED CONSTITUENT CONCENTRATIONS EXCEEDED EPA DRINKING WATER STANDARDS (SITE 2)

Constituent	Background Wells		Downstream Wells†	
	Phase I	Phase II	Phase I	Phase II
Cd	1-2*	0-5	1-6	0-5
Cu	0-2	0-5	0-6	0-5
Fe	2-2	5-5	5-6	5-5
Hg	0-2	0-5	1-6	3-5
Pb	0-2	1-5	5-6	5-5
Zn	0-0	0-5	0-2	1-5
Cl	2-2	0-5	4-6	0-5
SO_4	2-2	0-5	0-6	1-5
TOC	2-2	2-5	5-6	5-5

* The first number indicates number of times standard was exceeded; the second number is sample population.

† Off-site shallow well was dry during Phase II monitoring.

Background Groundwater--

The background groundwater was found to contain cadmium, iron, lead, chloride, sulfate, and TOC at levels that exceeded the drinking water standards on one or more occasions.

The concentrations of cadmium and lead exceeded the standards one out of seven occasions. The contamination by these metals was not confirmed, since their concentrations on the other six occasions were either nondetectable (particularly cadmium) or did not approach the standards. Concentrations of chloride and sulfate exceeded the standards only in Phase I. Apparently, the background well in Phase II was located sufficiently outside the influence of the salt water. Concentrations of iron and TOC exceeded the standards seven and four times, respectively, out of seven occasions. Iron concentrations, however, were not exceedingly high in the Phase II background well (0.42 to 1.20 ppm).

Downstream Groundwater--

The downstream wells showed cadmium, iron, mercury, lead, zinc, chloride, sulfate, and TOC as exceeding drinking water standards at least once during the study period (Table 21).

Cadmium and zinc each exceeded the standard one out of 11 occasions. However, the data showed that their concentrations in the other 10 samples were similar to those in the background levels and no contamination by these metals was indicated in the downstream groundwater. Chloride exceeded the standard four out of 11 samples that occurred in Phase I. Although sulfate exceeded the standard only once, its concentrations were consistently high in the downstream groundwater. Based on the high background levels of chloride and sulfate, particularly in Phase I, concentrations of these two contaminants in the downstream wells was probably due to saltwater intrusion. The groundwater intercepted by the downstream well was possibly a mixture of water from the nearby lakes and leachate leaving the landfill.

Since iron, lead, and TOC exceeded the drinking water standards on 10 of 11 occasions, indications were that groundwater from the downstream wells was contaminated with these constituents. The concentrations of lead were two to three times higher than the standard (0.05 ppm) and posed serious problems to the quality of this groundwater. On the other hand, TOC levels in some instances were comparable to background levels; thus, no serious contamination by organic species was indicated.

Preliminary results obtained indicated that groundwater in the vicinity of the landfill was affected by the salt water to varying degrees. The quality of background groundwater was poor, as shown by relatively elevated levels of iron, chloride, sulfate, and TOC. Since the lower portion of much of the landfill lies below the water table, the leachate and contaminants from the landfill can migrate readily into the groundwater. Indications were that the groundwater downstream from the landfill was contaminated to a certain extent with lead, iron, sulfate, chloride, and organic constituents.

Overall, except for lead, the impact of the landfill is probably of little consequence. While leachate is being generated, the relative impacts of sludge disposal are difficult to separate out from the highly variable ambient concentrations existing around the landfill.

SITE 3

Soil Analyses

During drilling of the in-refuse well, soil samples were taken from the refuse-soil interface and soil-groundwater interface at 7.3 to 7.6 m and 11.0 to 11.3 m, respectively. Results of the sequential extraction with water and concentrated nitric acid are shown in Table 22.

The soil at the lower depth contained significantly higher levels of TOC and COD than soil at the upper layer, which would indicate a significant migration and/or accumulation of both organic and reduced chemical species in the soil-groundwater interface. The groundwater table hovered within 1 m of the bottom of the fill; the data, therefore, suggest that leachate emanating from the landfill has migrated into the underlying soil groundwater.

A large portion of calcium at the refuse-soil interface was soluble in water, while the heavy metals were primarily found in the acid-extractable form. Concentrations of lead were slightly higher than those commonly found in soils, while concentrations of other heavy metals, particularly mercury, were lower (1, 2). No differences were found in heavy metal concentrations between the two sampling depths.

Nitrogen was present primarily in the organic form. The low nitrate levels and high moisture contents suggest a reducing regime in the soil.

Sludge Analyses

Grab sludge sample results showed considerable variation in constituent concentrations depending upon the sampling date (Table 22). More than 50 percent of the TKN was ammonium, which exceeded the median concentration reported by Sommers (9).

TABLE 22. ANALYTICAL RESULTS FOR DISPOSAL SITE 3, PHASE I*

	Soil Samples Taken Below Landfill During Drilling of In-Refuse Well			
	Refuse-Soil Interface (7.3 to 7.6 m)		Soil-Groundwater Interface (11 to 11.3 m)	
	Water	Acid	Water	Acid
Constituent†	6/24/75		6/24/75	
pH	7.2		6.8	
TOC	240		600	
COD	319		1849	
TKN	250		118	
NH_4-N	34		4.5	
NO_3-N	2.5		<0.4	
Cl	250		223	
SO_4	60		80	
Ca	1000	1500	135	14500
Cd	<0.03	0.27	<0.03	0.33
Cr	<0.30	3.68	<0.30	3.03
Cu	0.20	7.30	<0.20	5.83
Fe	0.3	3293	1.3	3742
Hg	0.009	0.006	0.007	0.005
Pb	0.2	12.6	<0.2	13.0
Moisture, %	25.1		24.7	

TABLE 22. (continued)

Constituent†	Sludge# Water 10/14/75	Sludge# Acid 10/14/75	Sludge# Water 6/3/76	Sludge# Acid 6/3/76	Background Groundwater 9/19/75
pH	5.4				7.8
Tot. Solids					991
TOC	7333		65714		11
COD	11925				34
MBAS			1.0		
TKN	616				1.3
NH_4-N	375				1.0
NO_3-N	1.9				.91
Cl	51		120		38
SO_4	10		38		185
Ca	300	1000			230
Cd	<0.04	0.60		1.2	0.009
Cr	1.25	33.50		63	0.02
Cu	0.24	6.00		44	0.018
Fe	29	650		2125	1.24
Hg	0.0003	0.002		<0.004	0.0004
Ni				5.9	
Pb	0.5	31.0		75	0.036
Zn				238	
Moisture, %	90		78		

TABLE 22. (continued)

Constituent †	Offsite Well (Shallow) 7/8/75	9/19/75	10/15/75	6/3/76
pH	6.7	7.4	6.7	
Tot. Solids	2379	3403	2040	
TOC	550	33	17	40
COD	861	50	32	
MBAS				<0.01
TKN	0.3	6.6	0.9	
NH_4-N	<0.1	4.6	0.5	
NO_3-N	0.10	<0.02	0.28	
Cl	3	50	60	56
SO_4	35	30	40	30
Ca	196	170	290	
Cd	0.007	0.008	0.004	0.007
Cr	0.17	<0.01	0.03	0.02
Cu	0.100	0.150	0.020	0.08
Fe	87.4	0.33	2.58	30
Hg	0.005	0.0002	0.0004	<0.0002
Ni				0.11
Pb	0.16	0.09	0.10	0.09
Zn				0.32

* Soil and sludge were extracted with water and concentrated nitric acid. Sampling dates are also indicated.

† Concentrations are expressed as mg/kg of dry soil, mg/kg of wet sludge, mg/l of groundwater or leachate, and most probable number/100 ml (100 g) for fecal bacteria count.

# Moisture contents were 89.9 and 78 percent for the 10/14/75 and 6/3/76 samples, respectively.

All of the heavy metals were within the ranges but less than the median concentrations found in over 250 sewage sludges reported (9).

Leachate Analyses

The leachates collected in Phases I and II were analyzed for several contaminants, particularly heavy metals (Table 23).

Phase I leachates showed the characteristically high levels of TOC, COD, and ammonium usually observed in landfill leachates. Nitrate was not detected, indicating the anaerobic nature of the leachate, while calcium, iron, and lead showed relatively high concentrations that fluctuated widely with time.

Concentrations of most contaminants measured in Phase II were lower than those of Phase I. Chromium, copper, cadmium, chloride, and sulfate levels in the leachates were low, while mercury was not detected. The data showed no trend or correlation among the various contaminant concentrations.

Gas Composition in In-Refuse Well

Gas samples collected from the in-refuse well between July and October 1975 were analyzed for methane, carbon dioxide, oxygen, and nitrogen (Table 24).

The July and October upper samples and the September lower sample were contaminated with air during sampling or shipping, as shown by the atmospheric values of oxygen and nitrogen. Concentrations of the four gases in the July and October samples were similar, with methane and carbon dioxide averaging 59.5 and 37.0 percent, respectively. These methane levels are similar to those found in many landfills.

Groundwater Analyses

Both background and off-site well groundwaters were monitored. Phase I background groundwater samples were taken from a privately owned well located southeasterly of the landfill site; Phase II background samples were obtained from the project well northeasterly of the site. There were four pneumatic ejector-type sampling probes inside the project background well at depths of 6.1, 9.1, 12.2, and 15.9 m.

The Phase I off-site well (OS-X), a shallow well, was westerly of the landfill site with one sampling level (at 7.3 m). Six new off-site wells (OS-1 to OS-6) with pneumatic ejector-type sample probes were installed in Phase II. These six wells formed a control volume below the groundwater table extending from the west to southwest boundaries of the site. Analytical data for Phases I and II are presented in Table 22 and in Table 3 of Appendix E, respectively.

TABLE 23. CHEMICAL ANALYSIS OF LEACHATE FROM IN-REFUSE WELL (SITE 3)

Constituent*	Phase I			
	7/8/75	9/19/75	10/15/75	6/3/76
pH	6.7	7.6	7.5	
Tot. Solids	13290	8111	5805	
TOC	7200	11333	14267	1030
COD	19552	23283	20302	
MBAS				
TKN	759	3236	3545	
NH_4-N	605	2468	3407	
NO_3-N	<0.02	<0.02	<0.02	
Cl	28	112	31	1160
SO_4	430	2	1	8
Ca	2070	437	111	
Cd	0.007	0.021	0.008	0.002
Cr	0.15	0.10	0.17	0.04
Cu	0.050	0.020	0.054	<0.1
Fe	20.6	11.1	10.4	1.7
Hg	0.005	0.012	0.001	
Ni				0.15
Pb	0.37	0.73	0.18	0.03
Zn				0.08

TABLE 23. (Continued)

Constituent*	Phase II					
	11/1/76	1/20/77	3/8/77	5/10/77	7/18/77	9/12/77
Cd	0.005	0.005	0.003	0.005	<0.005	0.010
Cr	0.12	0.46	0.07	0.06	0.01	0.01
Cu	0.01	0.02	0.03	0.01	<0.01	0.01
Fe	6.5	9.1	15.0	17.0	24.8	16.0
Hg	<0.0002	<0.0002	0.0010	0.0003	0.0002	0.0002
Ni	0.02	0.30	0.28	0.08	0.05	0.04
Pb	0.150	0.065	0.470	0.240	0.140	0.090
Zn	0.16	1.80	0.41	0.65	<0.01	0.10
Cl	12	26	30	<2	19	11
SO_4	20	4	12	30	70	33
TOC	2240	2028	1790	8	70	76
Sp. Cond.	--†	25000	24000	--	7500	8000

*Specific conductance in μmhos/cm, all other constituents concentrations in ppm.

†Insufficient sample.

TABLE 24. GAS COMPOSITION AT SITE 3 IN-REFUSE WELL

	Sampling Date					
	7/8/75		9/19/75		10/15/75	
Gas Species	Upper	Lower	Upper	Lower	Upper	Lower
	%					
CH_4	--*	56.3	53.7	--	5.8	62.6
CO_2	0.1	39.6	33.6	--	1.4	34.3
O_2	21.2	0.9	2.8	21.2	16.4	0.6
N_2	78.7	3.2	9.8	78.8	76.4	2.5

*Below detection limit

Background Groundwater--

Judging from the groundwater flow patterns (Figure 47), the Phase I background well might have been contaminated by leachate from the landfill. The consulting geologist indicated that other land uses in the area might have caused changes of such magnitude in the original groundwater quality that sampling from no single background well could be reliable. However, because the Phase II project background well was located upstream and in the opposite direction of groundwater flow, it may still be useful for comparing groundwater quality changes due to the landfilling operations.

Concentrations of the selected contaminants in the project background well were well within the concentration ranges of most terrestrial waters (4). Concentrations of selected contaminants in the background groundwater varied with both time and depth in the Phase II monitoring. Chloride, sulfate, and TOC concentrations showed a decreasing trend since the winter of 1976. However, since no data is available after the autumn of 1977, it is not clear if there is a relationship between season and concentration. Monitoring for a minimum of two consecutive years is probably necessary in order to observe this relationship. Most trace metal concentrations showed higher levels in the summer. Although it is not clear if seasonal changes also affect the migration of these metals, it is quite possible that the higher concentration was due to the higher flow rate in the summer season, as was suggested in Site 1.

Contaminant concentrations were generally higher in the upper sampling levels than those in the lower levels. This was probably due to the high vertical flow (6) that leached more contaminants from the soil above to the sand layer where the sampling points were located.

Downstream Groundwater--

In comparison with Phase I, concentrations of lead, zinc, and probably iron in the OS-X well increased, while those of chloride decreased in the Phase II monitoring. There were also appreciable decreases in TOC concentrations following the first sampling in Phase II.

Phase II downstream well data showed that the concentrations of contaminants varied with depth, although no general trend was observed (Figures 48 to 54). It is not certain if there was any concentrated localized leaching into the underlying or downstream soil layers. However, this is quite possible, since the soils are somewhat inhomogeneous and an unsaturated flow might result in some locations, as will be discussed in more detail in the Environmental Impact Assessment. Another cause may be from the channels or cracks created in the clay layer by the operator during digging of pits. Among the contaminants studied, only TOC showed consistently higher concentrations in the groundwater of the upper soil layers.

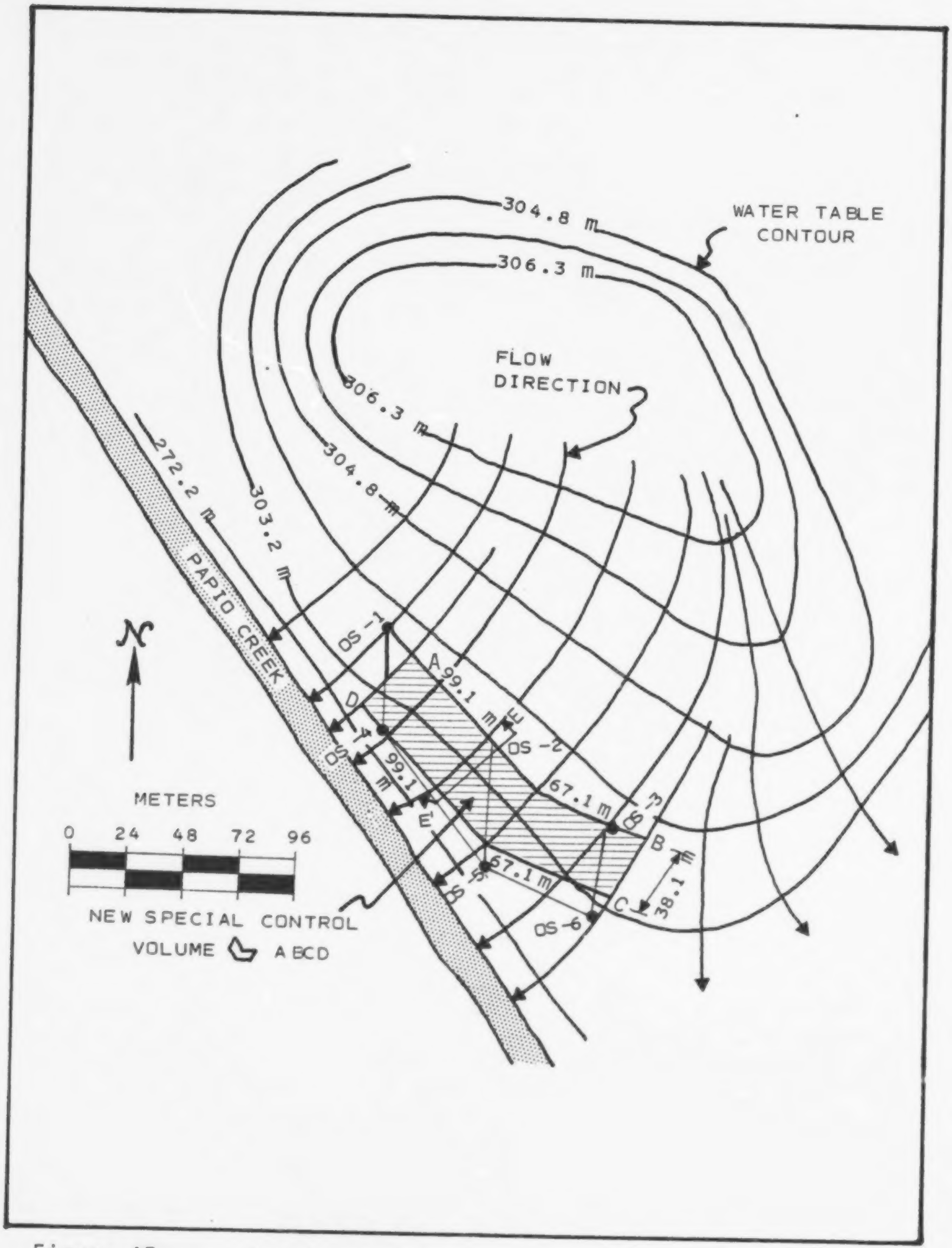
304.8 m
WATER TABLE
CONTOUR
306.3 m
FLOW
DIRECTION
306.3 m
304.8 m
303.2 m
272.2 m
PAPIO CREEK
N
OS -1
A
99.1 m
D
E
OS -2
OS -4
99.1 m
67.1 m
OS -3
E'
B
m
OS -5
67.1 m
C
38.1
OS -6
METERS
0
24
48
72
96
NEW SPECIAL CONTROL
VOLUME
ABCD

Figure 47. Configuration of water table, groundwater flow direction, and new special control volume of site 3.

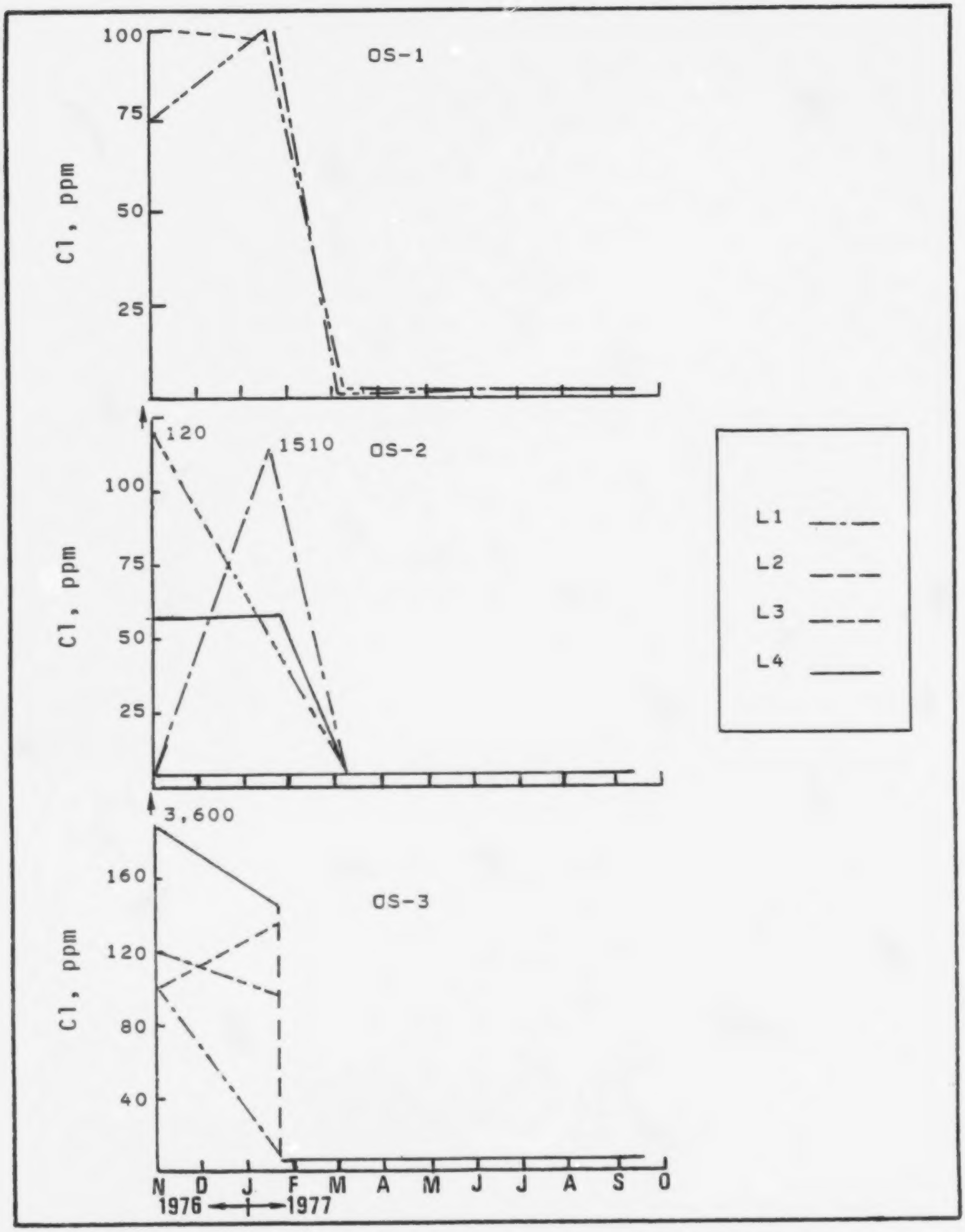

Figure 48. Cl levels in groundwater from six off-site wells (site 3).

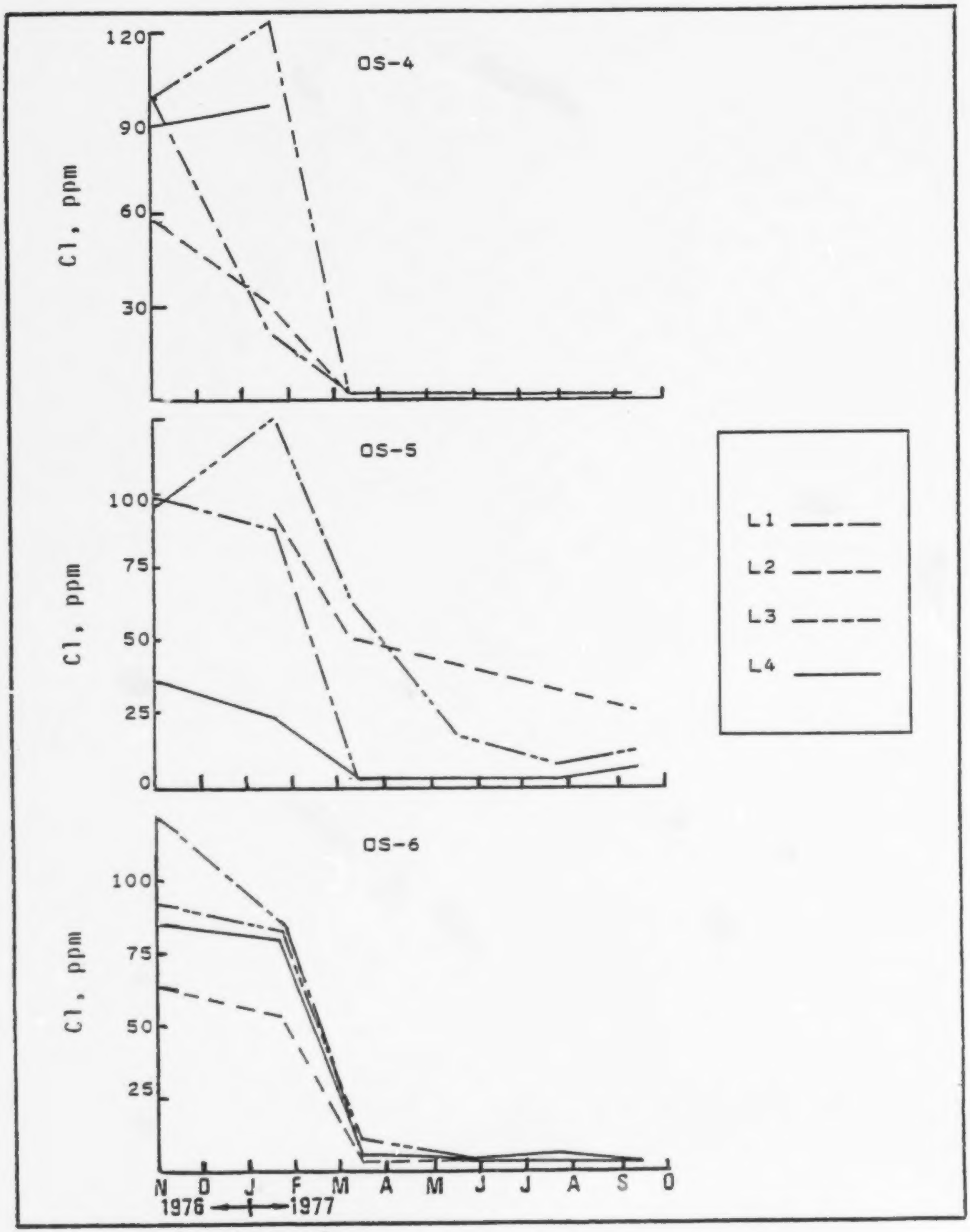

Figure 48. (Continued)

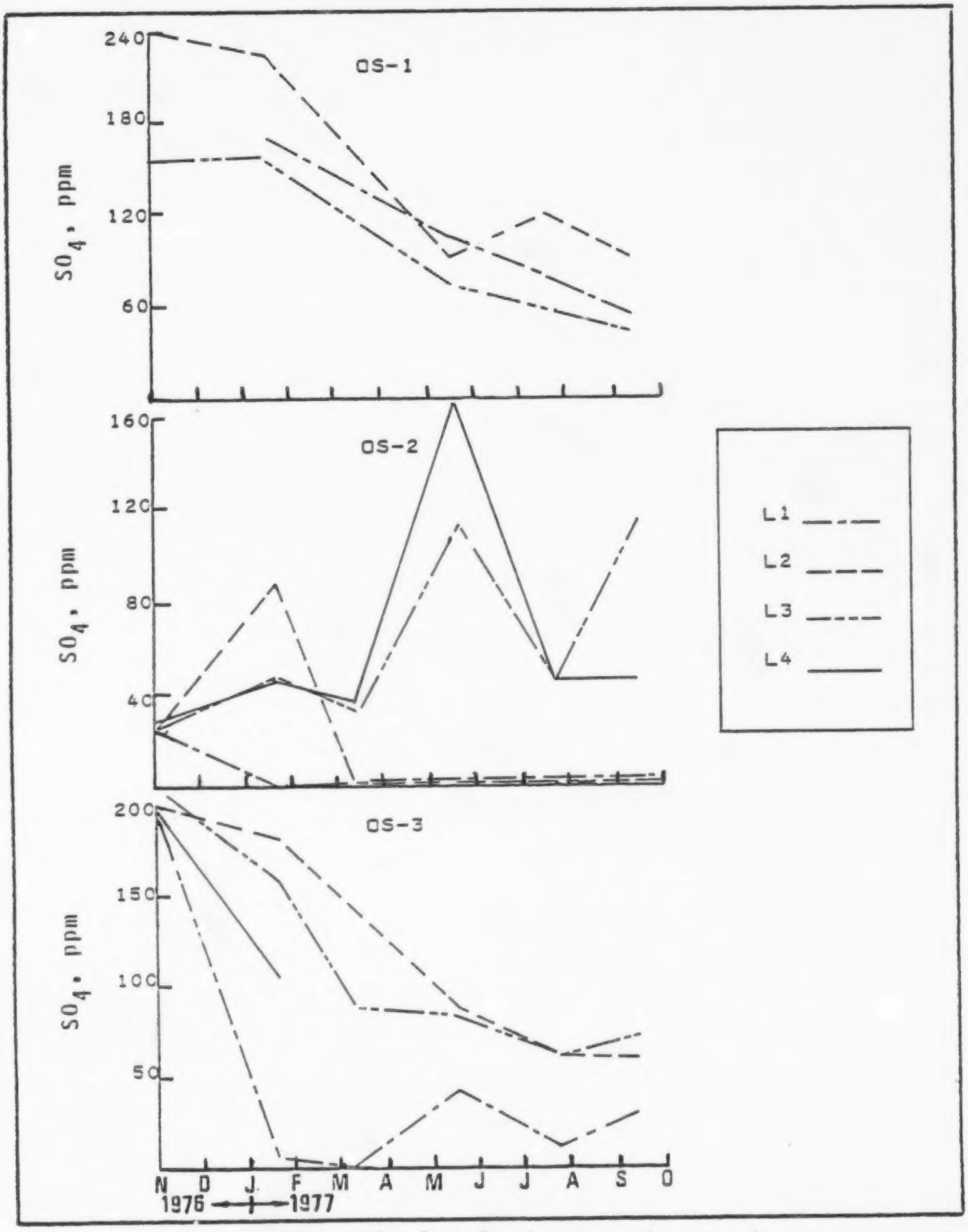

Figure 49. SO$_4$ levels in groundwater from six off-site wells (site 3).

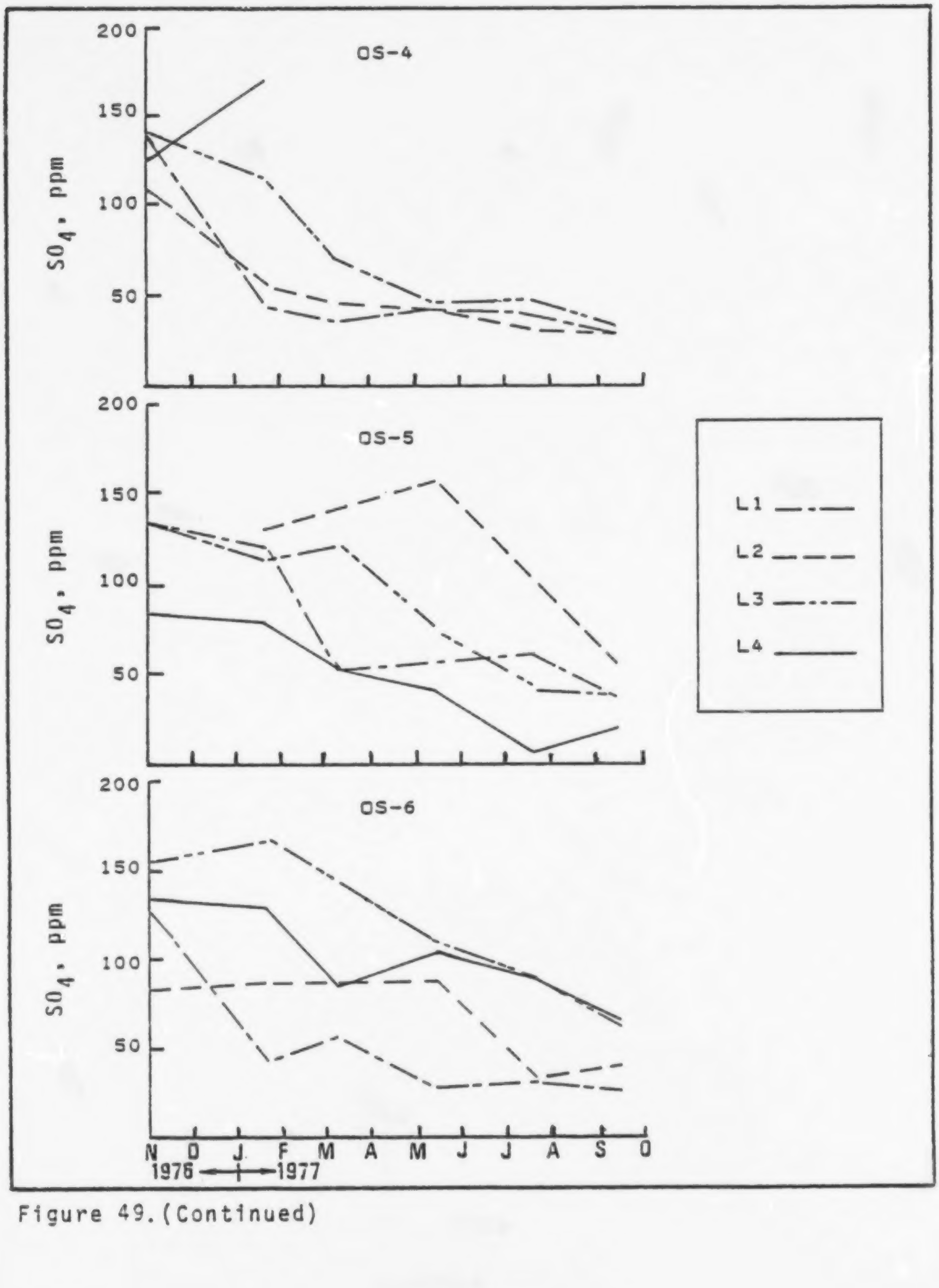

Figure 49. (Continued)

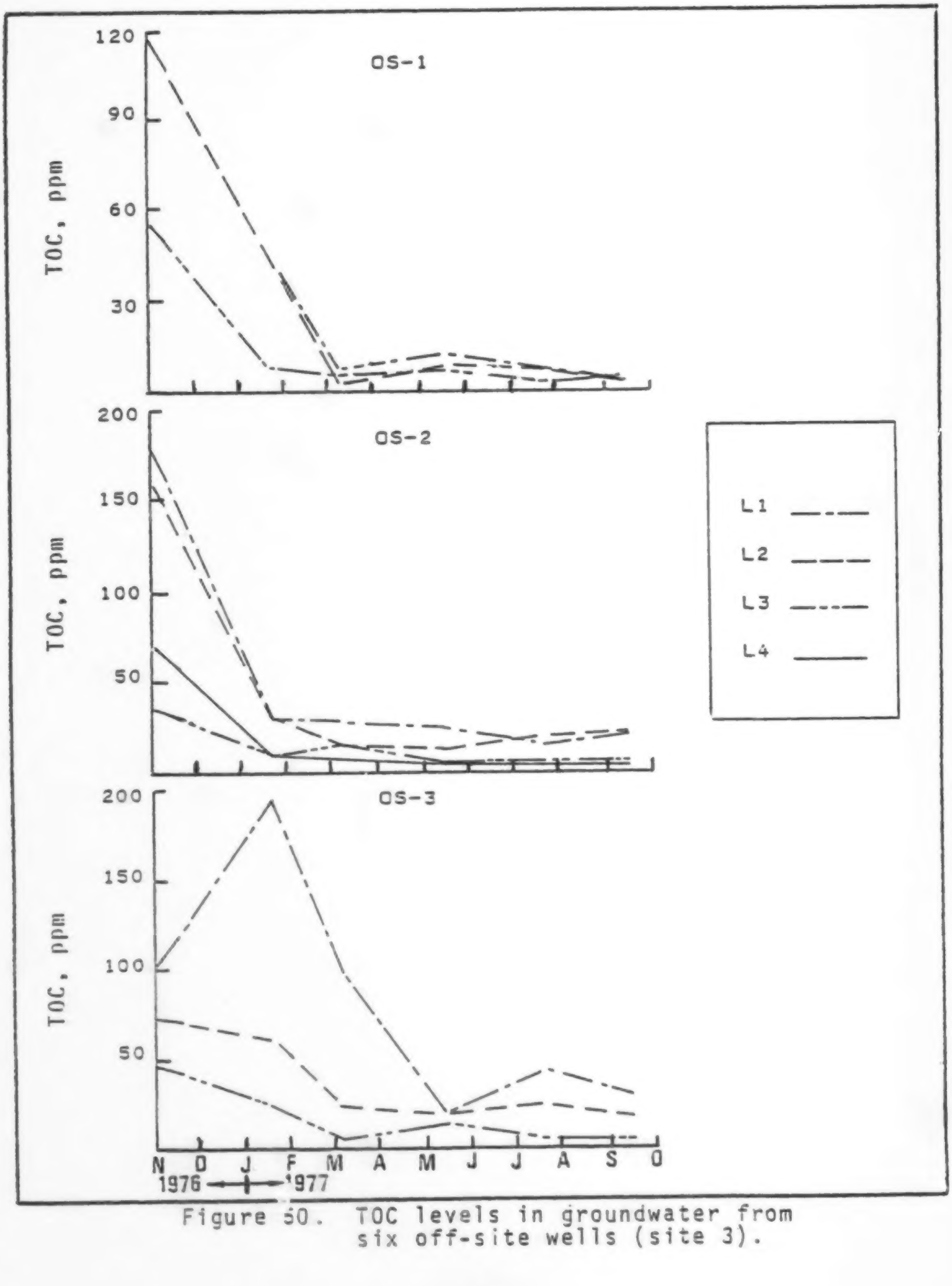

Figure 50. TOC levels in groundwater from six off-site wells (site 3).

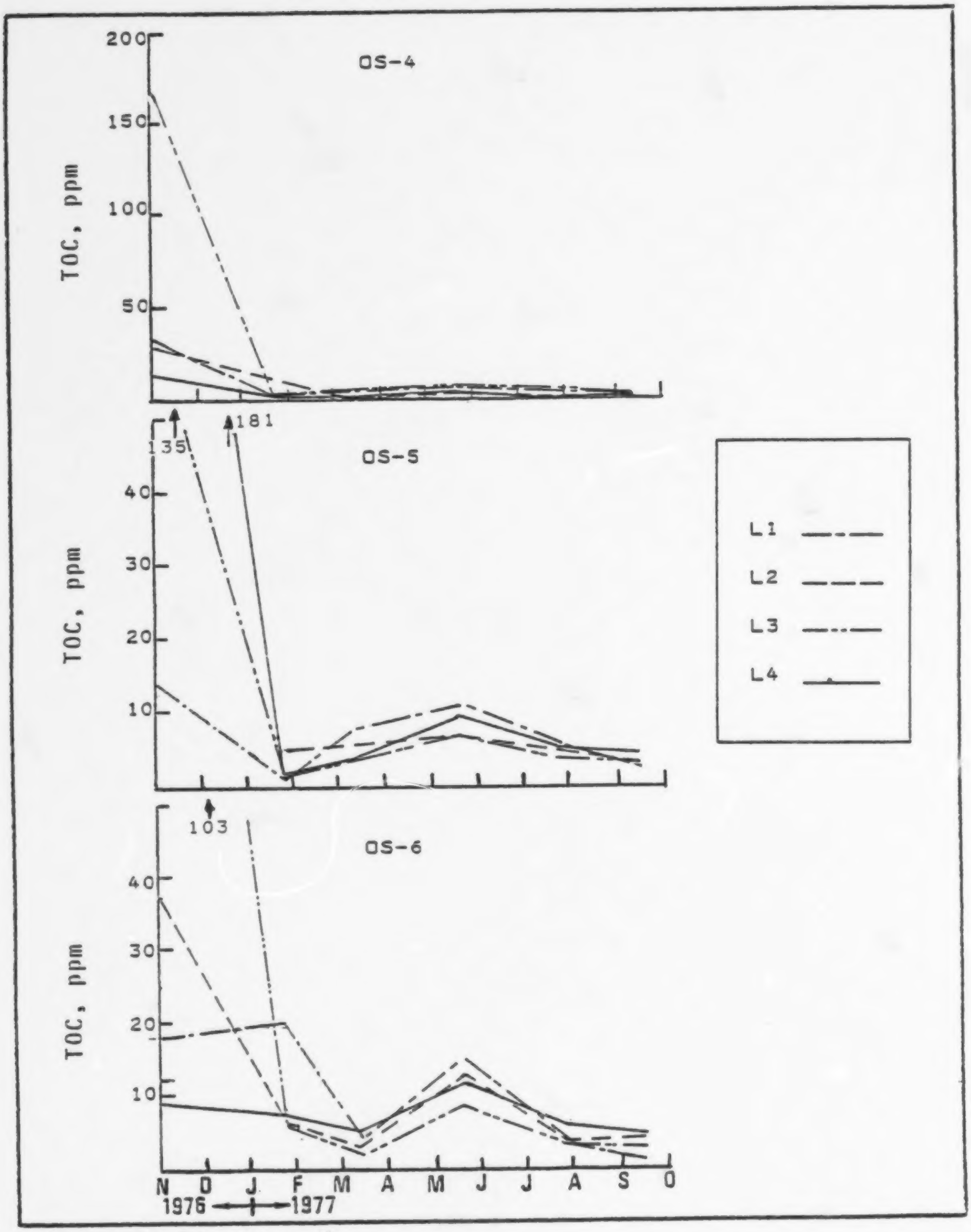

Figure 50.(Continued)

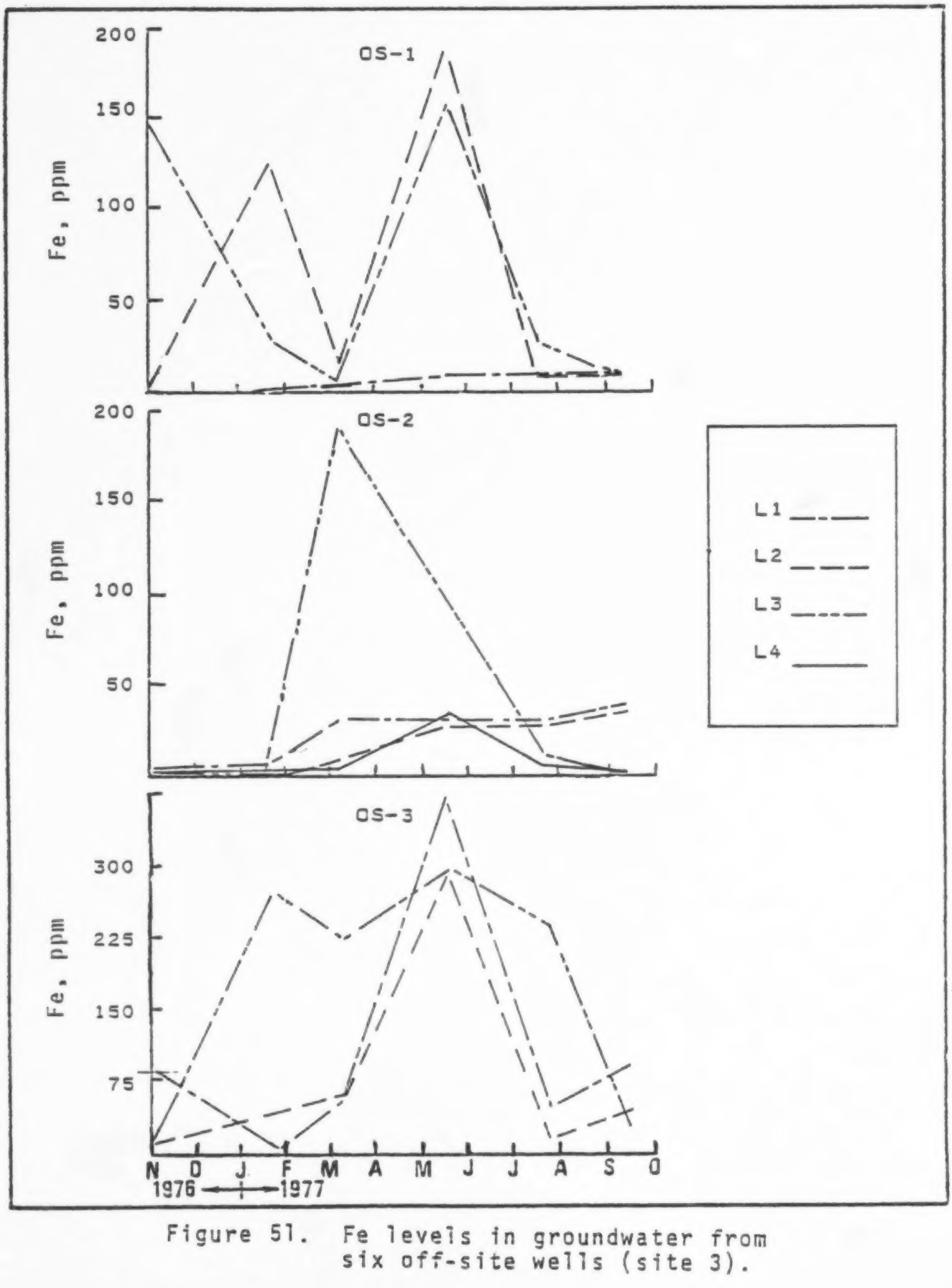

Figure 51. Fe levels in groundwater from six off-site wells (site 3).

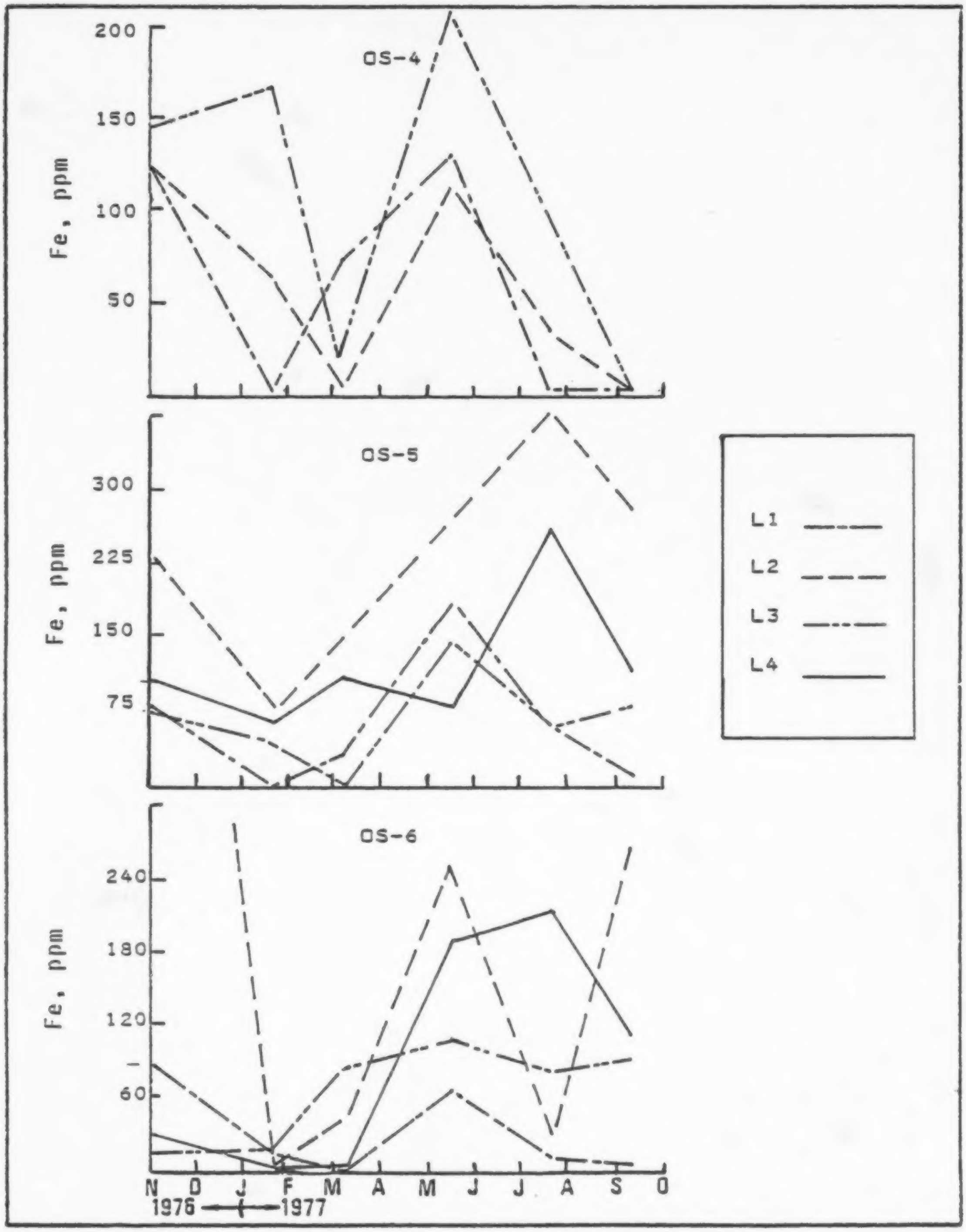

Figure 51.(Continued)

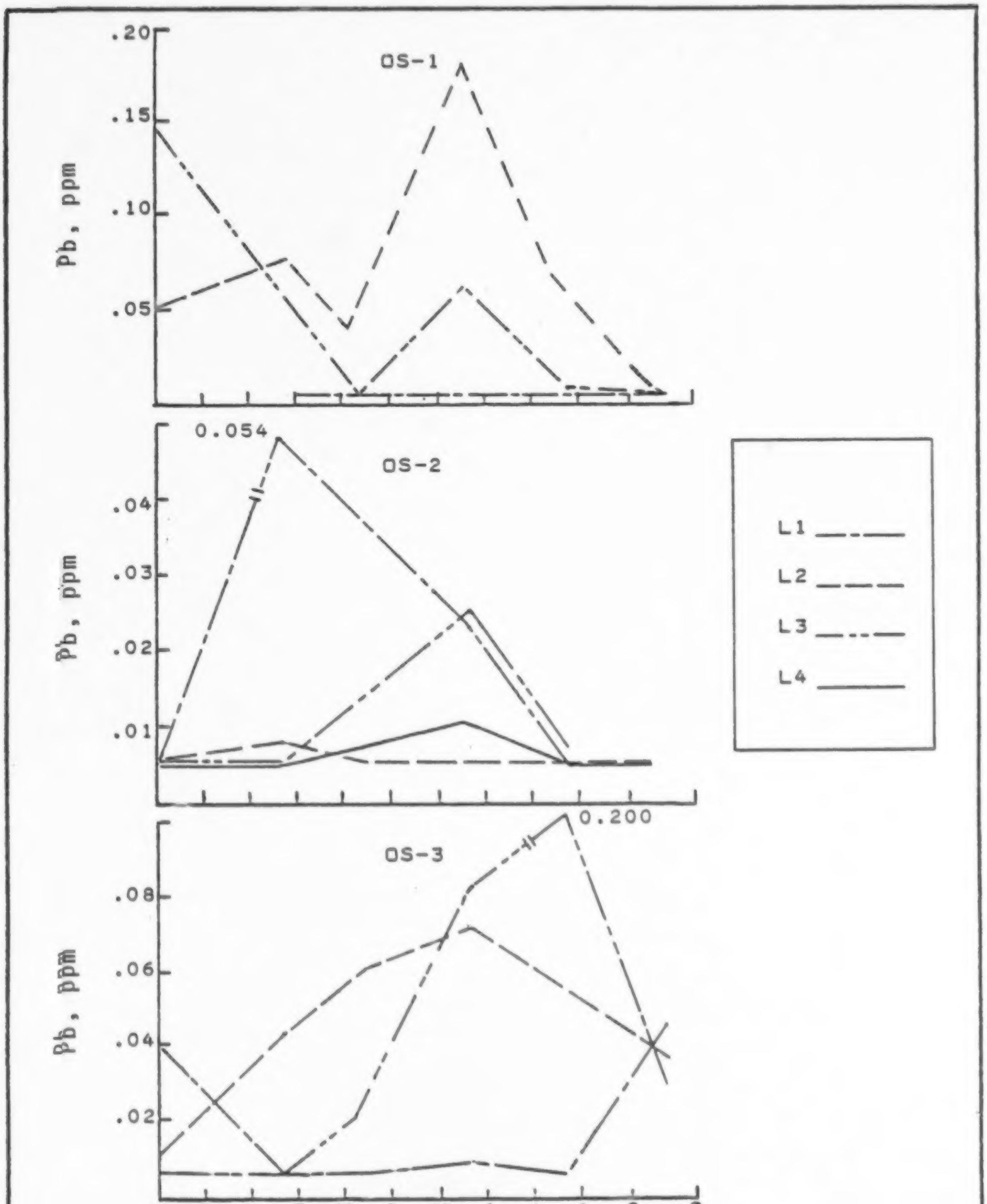

Figure 52. Pb levels in groundwater from six off-site wells (site 3).

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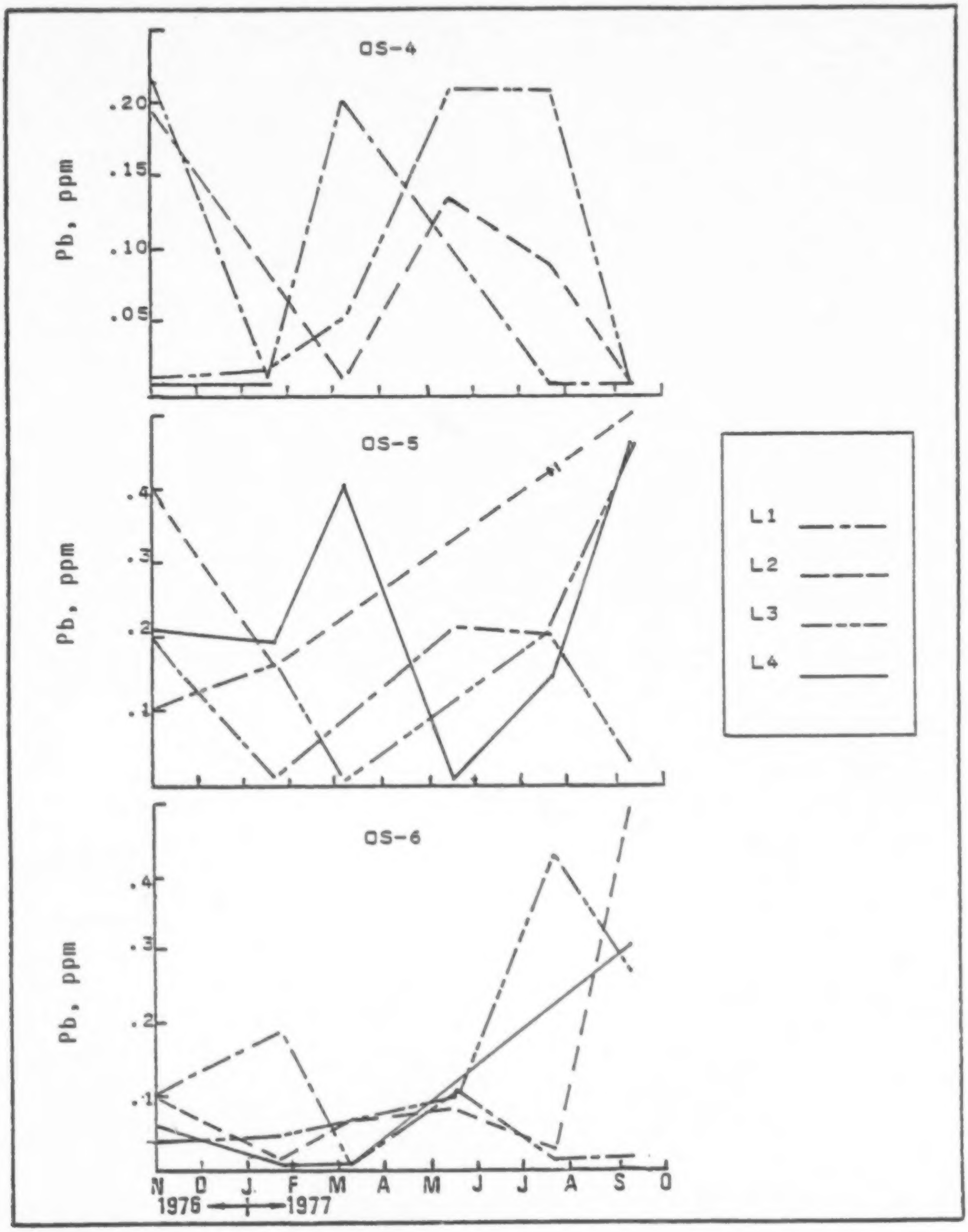

Figure 52.(Continued)

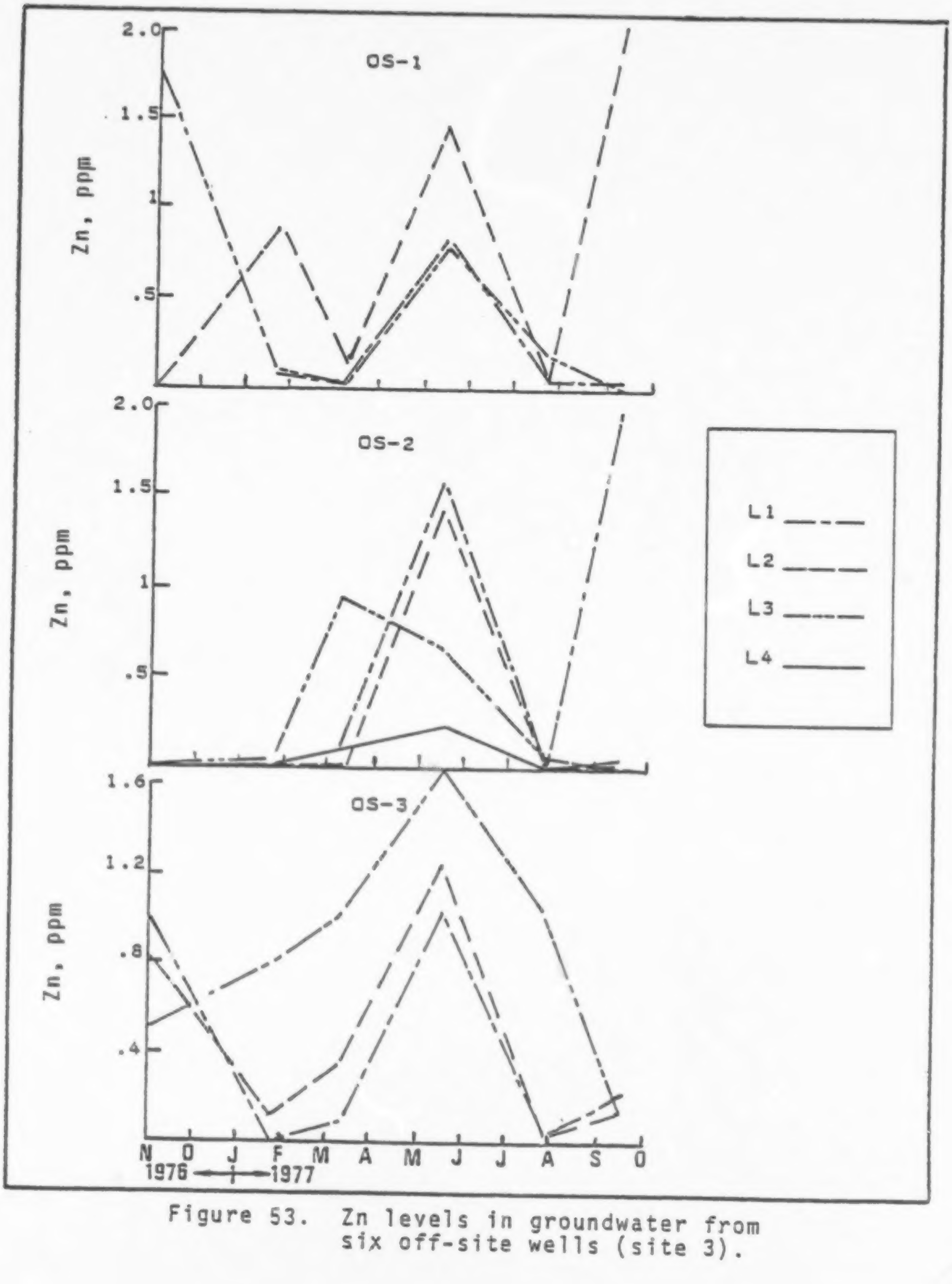

Figure 53. Zn levels in groundwater from six off-site wells (site 3).

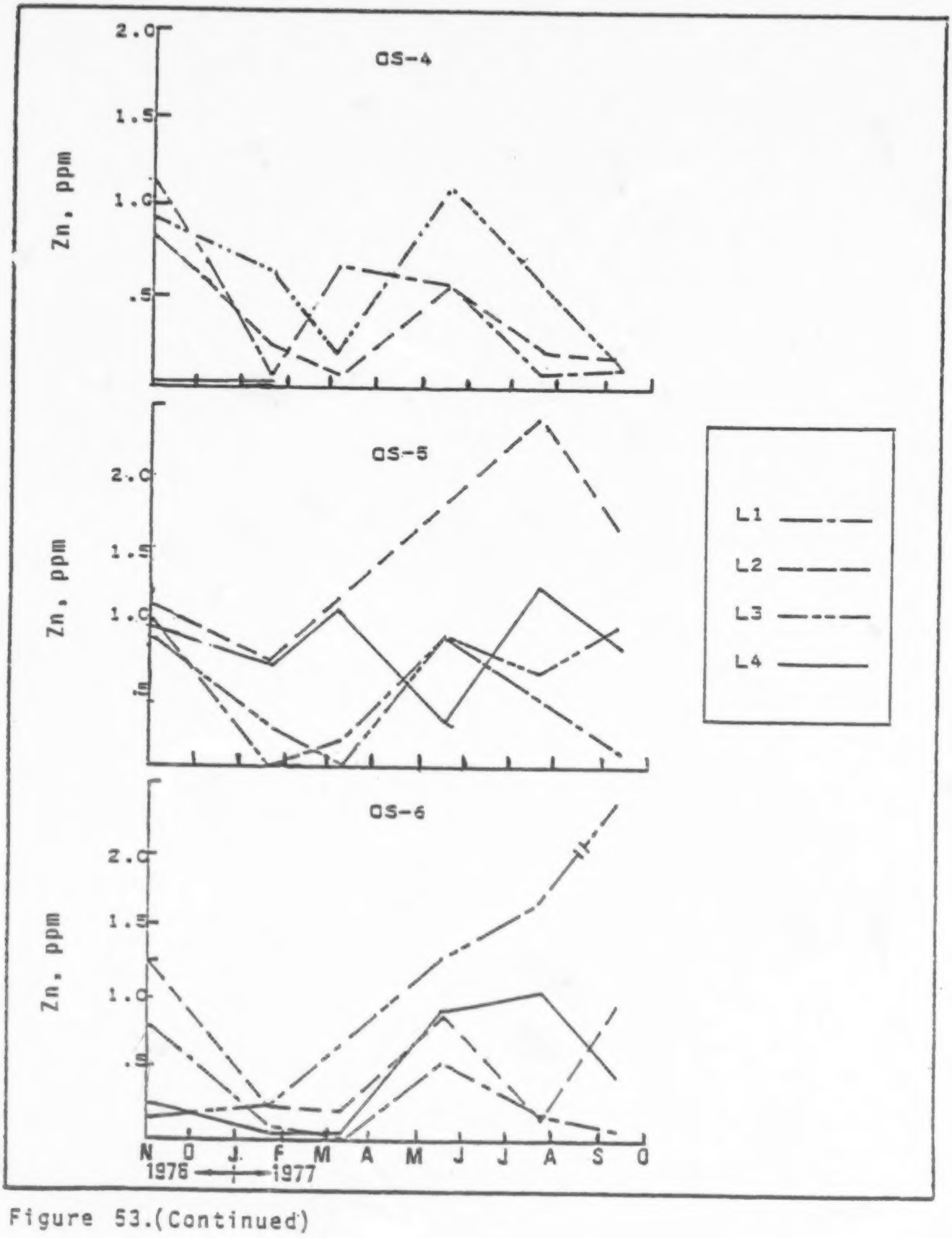

Figure 53.(Continued)

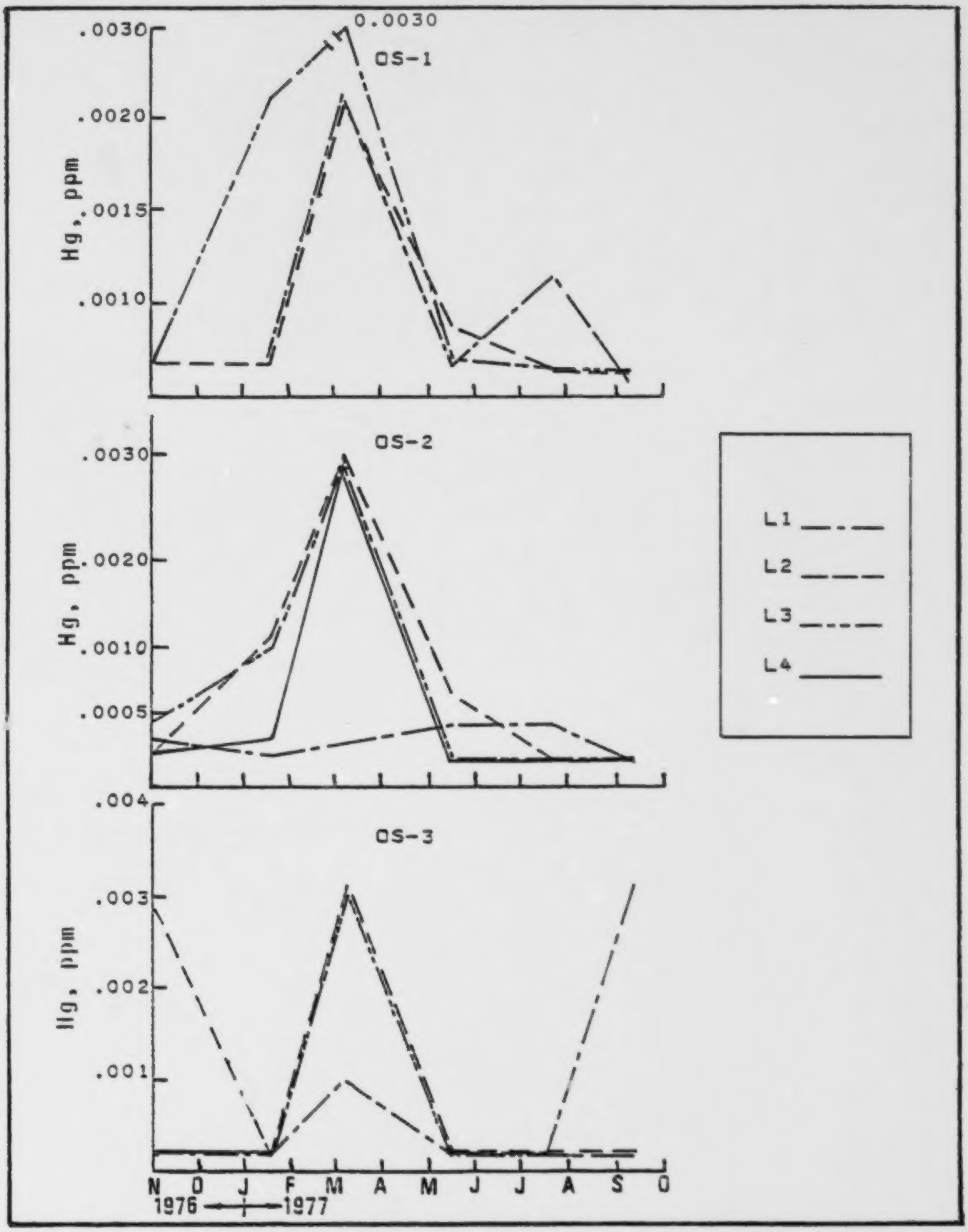

Figure 54. Hg levels in groundwater from six off-site wells (site 3).

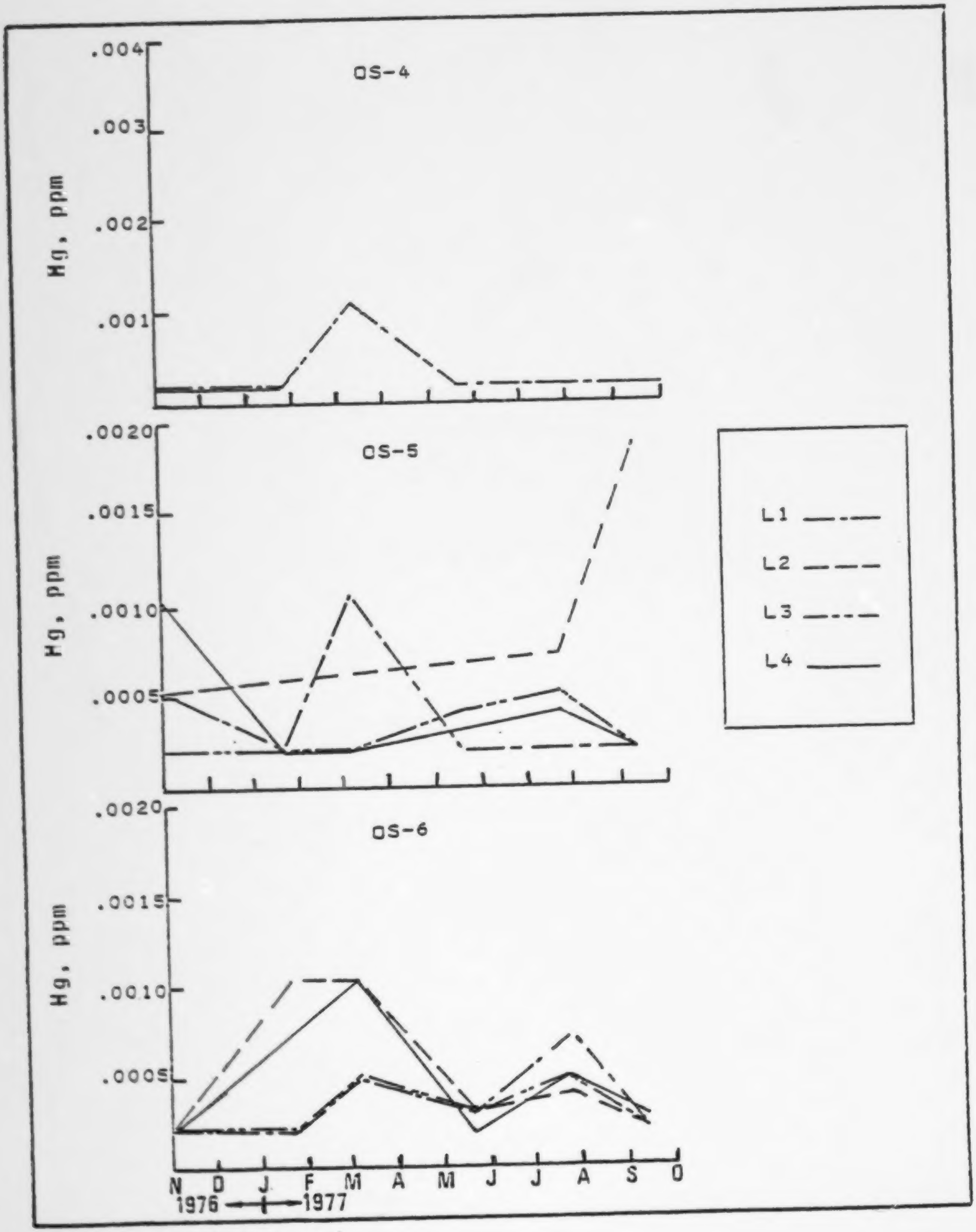

Figure 54.(Continued)

Concentrations of contaminants fluctuated over sampling time (Figures 48 to 54). While chloride was detected at relatively higher levels during the winter, most of its concentrations were close to 2 ppm in subsequent monitoring periods. It is not known if chloride concentrations would rise again next winter. A longer study time is needed to confirm such seasonal variation. The data for TOC and, to some extent, sulfate exhibited similar seasonal trends.

Among the trace metals in groundwater samples taken from the off-site wells, iron and most of the zinc levels were in the ppm range, others in the ppb range. Most of the results showed higher concentrations in the summer than any other season. Among the trace metals, mercury showed a slightly different pattern, peaking around March and April and having a higher peak in the inlet than in the outlet face of the control volume.

Comparisons of Contaminant Concentrations from Different Sources--

Comparisons between the migration trends and levels of contaminants in the in-refuse well leachates, background, and off-site well groundwaters are given in Figures 55 to 57. Both TOC and lead levels were higher in the in-refuse well leachates than in the background or downstream groundwater; the opposite trends were noted for those of iron and sulfate. Concentrations of other contaminants in the background or off-site well groundwaters varied. The relatively low sulfate levels could be due to the reducing characteristics of the in-refuse leachate. However, the relatively low iron levels could be associated with the low iron content of the sludge.

While concentrations of chloride, sulfate, mercury, iron, lead, and zinc were higher in the off-site well groundwaters than in the background groundwater, TOC showed only a minimal variation. The increase in sulfate in the downstream groundwater was probably due chiefly to oxidation of sulfide species from the landfill. This is usually accompanied by an increase in most trace metal concentrations, except iron, and can be attributed to the formation of other metallic solids (e.g., carbonates) with higher solubility.

Special Control Volume Analyses

Flow Calculation--

The geologic formation that controls the groundwater hydrology at this site can be divided into four strata: upper clay, middle clay, lower clay, and sand. The approximate permeability of these soil layers were calculated by the geological consultant and are as follows:

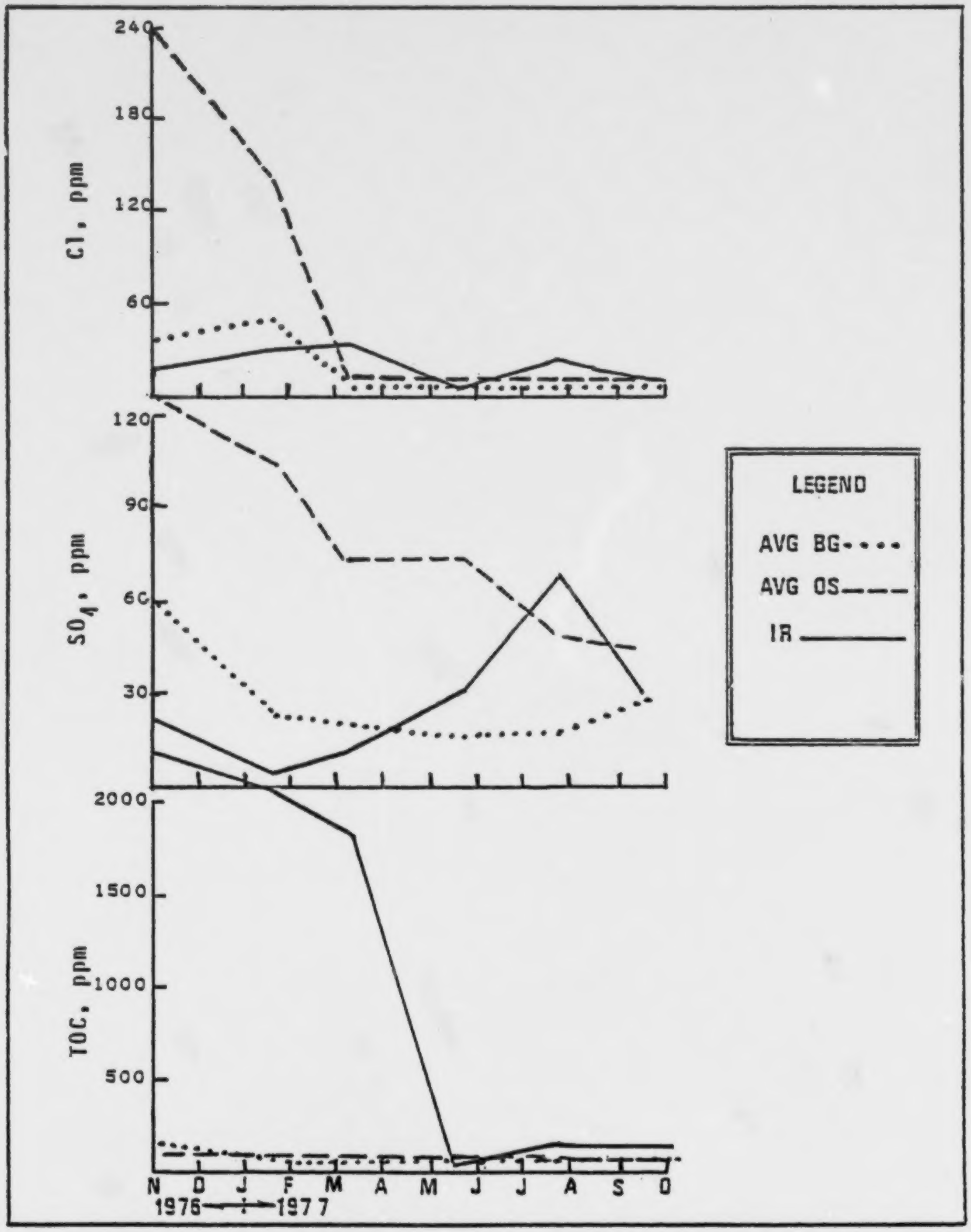

Figure 55. Cl, SO_4, and TOC levels in groundwater and leachate (site 3).

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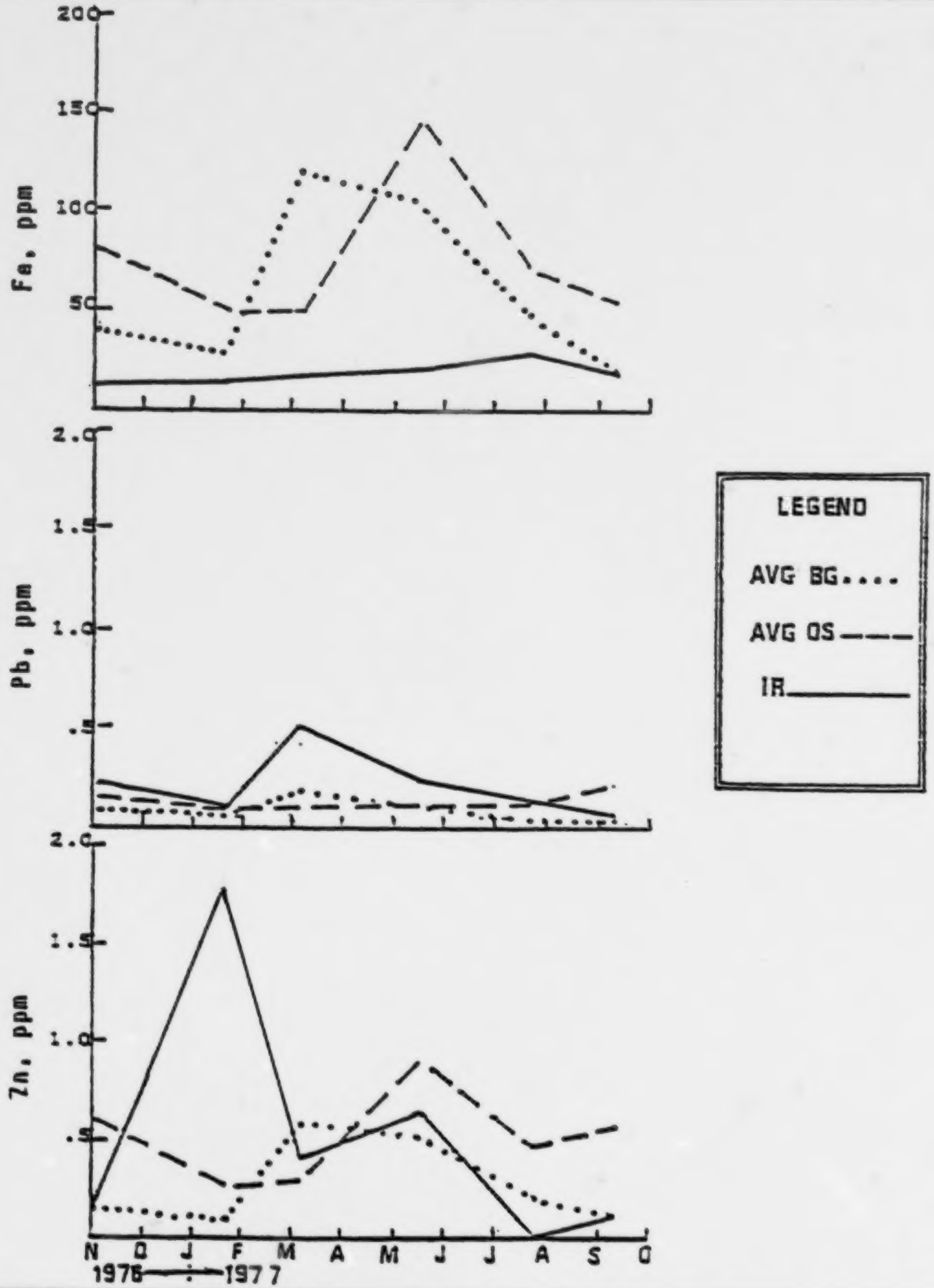

Figure 56. Fe, Pb, and Zn levels in groundwater and leachate (site 3).

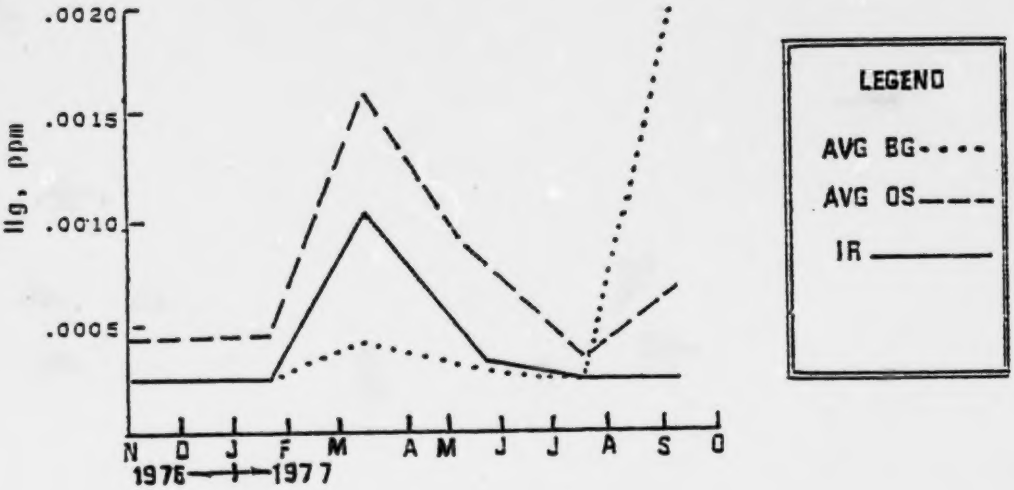

Figure 57. Hg levels in groundwater and leachate (site 3).

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	Permeability (K)	
Geologic Layer	ft/day	cm/sec
Upper clay	5	1.76×10^{-3}
Middle clay	0.0069	2.44×10^{-6}
Lower clay	0.367	1.29×10^{-4}
Sand	200	7.06×10^{-2}

The configuration of the surface or upper water table is shown in Figure 47 (p. 159). Confined by the clay layer, groundwater is mounded in the landfill area, while the regional water table generally slopes toward the creek channel. Groundwater flow in the sand and clay formations is probably at right angles to the water table contours. Therefore, the flow is generally toward the creek and down valley.

Flow velocities could vary with changes in piezometric groundwater elevations. However, because of the complex water mounding in the vicinity of the landfill, available data on groundwater elevations were generally inadequate to perform the necessary detailed calculations. It was assumed that flow velocity variations were negligible. Data on the direction and magnitude of the horizontal and vertical components of groundwater flow in the different strata in the control volume have been provided by the consultant geologist (6):

Formation	Flow Component	ft/day	cm/day
Lower clay	Vertical	1	30.5
	Horizontal	0.012	0.37
Sand	Horizontal	25	762

Although the vertical flow in the sand formation could be slowed down by the relatively large regional groundwater flow, at this site the vertical flow in the lower clay (30.5 cm/day) was significant enough to affect the flow pattern in the sand layer.

Control Area and Flow Rate--

As shown in Figure 47, the horizontal flow direction was not parallel to the presumed longitudinal axis. Thus, the flow passing the inlet face (formed by OS-1, OS-2, and OS-3) was not completely the same as the one passing out the outlet face (formed by OS-4, OS-5, and OS-6). Therefore, a new horizontal control shape had to be constructed according to the horizontal flow vectors, as shown in Figures 47 and 58 (shape ABCD). Using the rule suggested in Section 5, a subarea A_{ijk} can be formed, assuming that the contaminant concentration at any sampling well can be applied halfway to the next sampling well. Thus, the subareas of the vertical inlet face can be formed

(Figure 58), as suggested by Thiessen (3). The calculated areas for each individual A_{ijk} are listed in Table 25.

The top and bottom boundaries of the control volume should also be formed by the vertical flow direction. In order to obtain this new shape, it is assumed that the original vertical boundaries range in elevation from 289.6 to 298.8 m, with a lower clay layer 1.07 m thick and a sand layer 8.08 m thick. Since the horizontal flow in the lower clay layer (Figure 59) was very small compared to the vertical flow, the shape would not be changed significantly. However, because of the continuous input of water through the lower clay and sand boundaries, the horizontal outlet section in the sand layer will be increased by a small quantity of V_v. The value of V_v can be determined as follows:

$$\text{Vertical inlet flow rate} = 1850\ \text{m}^3/\text{day}\ \text{(Table 25)} \tag{49}$$

$$\text{Horizontal inlet flow rate} = 10220\ \text{m}^3/\text{day}\ \text{(Table 26)} \tag{50}$$

$$\begin{aligned}\text{Total inflow} &= 1850\ \text{m}^3/\text{day} + 10220\ \text{m}^3/\text{day} \\ &= 12070\ \text{m}^3/\text{day}\end{aligned} \tag{51}$$

Assuming that the horizontal flow velocity in the sand layer is kept constant (762 cm/day), the area of the outlet plane becomes

$$A_{H,\ \text{out}} = \frac{12070\ \text{m}^3/\text{day}}{762\ \text{cm/day}} = 1580\ \text{m}^2\ \text{(Table 27)} \tag{52}$$

This outlet area is located chiefly on the sand layer, because the lower clay layer had extremely low horizontal flow velocity. Therefore, the depth increase on the outlet plane becomes

$$\begin{aligned}\frac{A_{H,\text{out}} - A_{H,\ \text{in}}}{\text{width of the outlet plane}} &= \frac{1580\ \text{m}^2 - 1340\ \text{m}^2}{166\text{m}} \\ &= 1.45\ \text{m}\end{aligned} \tag{53}$$

This depth increase results in the following angle for the groundwater down flow:

$$\begin{aligned}&\frac{1.45\ \text{m}}{\text{travel distance}} = \frac{1.45\ \text{m}}{38\ \text{m}} = 0.038 \\ &\theta = \tan^{-1} 0.038 = 2.2^\circ\end{aligned} \tag{54}$$

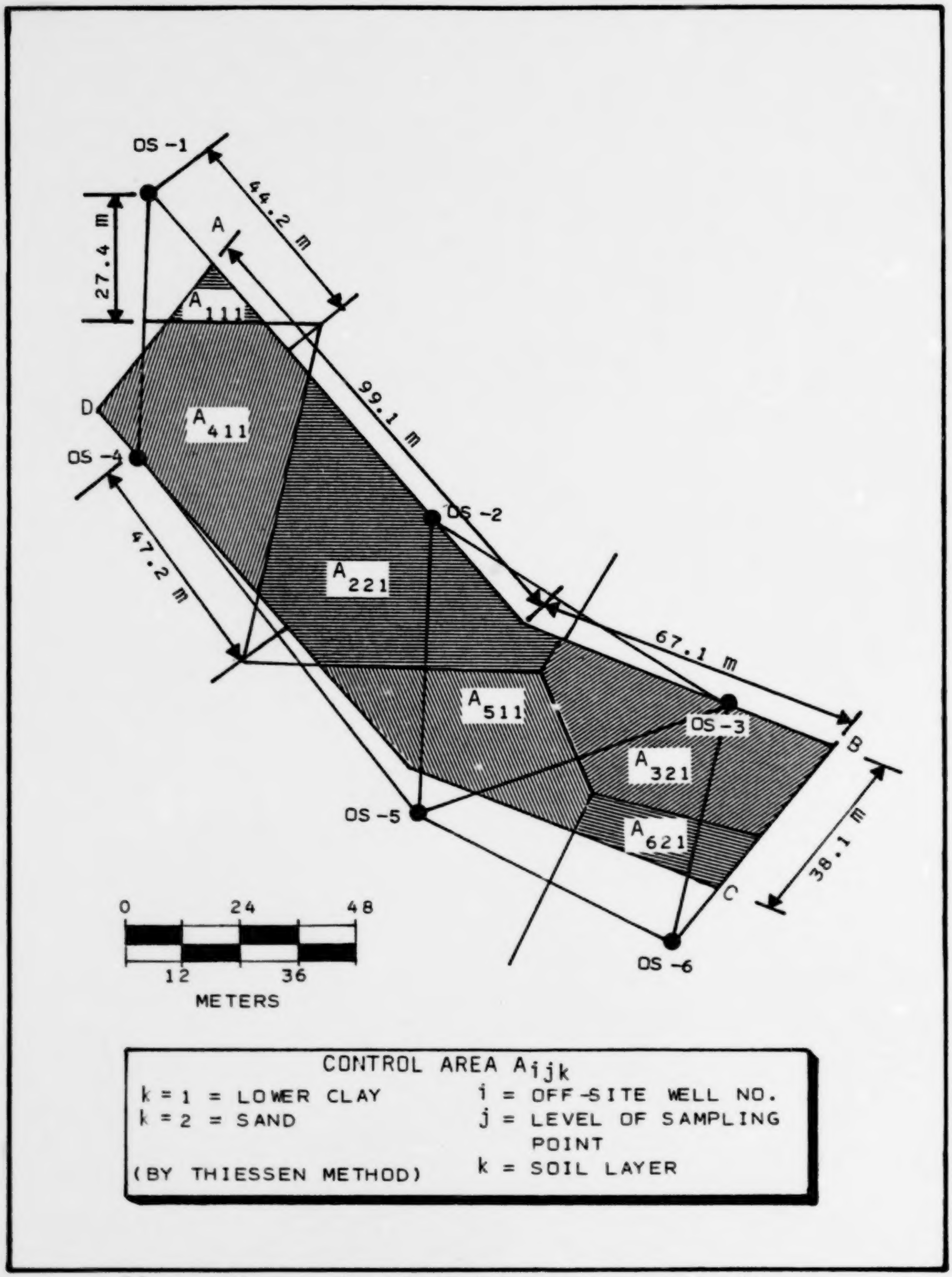
OS -1
44.2 m
27.4 m
A
A111
99.1 m
D
A411
OS -4
OS -2
47.2 m
A221
67.1 m
A511
OS -3
B
A321
OS -5
A621
38.1 m
C
OS -6
0
24
48
12
36
METERS
CONTROL AREA Aijk
k = 1 = LOWER CLAY
k = 2 = SAND
i = OFF-SITE WELL NO.
j = LEVEL OF SAMPLING POINT
k = SOIL LAYER
(BY THIESSEN METHOD)

Figure 58. Vertical inlet section of site 3.

TABLE 25. CONTAMINANT FLUX AND MASS THROUGH VERTICAL INLET SECTION OF SITE 3 (LOWER CLAY LAYER)

Period	Area symbol*	Area (m^2)	Q (m^3/d)	Cl^- C (ppm)†	Cl^- J (kg/d)#	Cl^- M (kg)**	$SO_4^=$ C (ppm)	$SO_4^=$ J (kg/d)	$SO_4^=$ M (kg)	TOC C (ppm)	TOC J (kg/d)	TOC M (kg)
11/1/76	A111	121	36.9	100	3.68	149	175	6.44	261	38	1.40	56.7
	A221	1,790	545	2	1.09	44.1	25	13.7	555	158	86.4	3,500
	A321	1,290	393	100	39.4	1,600	200	78.7	3,190	70	27.6	1,120
12/10/76	A411	1,400	427	100	42.8	1,700	140	59.9	2,430	35	15.0	608
	A511	1,090	332	97	32.1	1,300	130	43.1	1,750	14	4.64	188
(40.5d)	A621	390	119	63	7.49	303	80	9.52	386	32	3.81	154
12/10/76	A111	121	36.9	100	3.68	247	175	6.44	432	38	1.40	93.8
	A221	1,790	545	2	1.09	73.0	83	45.4	3,040	34	18.6	1,250
1/20/77	A321	1,290	393	140	55.1	3,690	180	70.9	4,750	61	24.0	1,608
	A411	1,400	427	27	11.5	770	50	21.4	1,430	6	2.57	172
2/15/77	A511	1,090	332	82	27.2	1,820	115	38.1	2,550	1	0.330	22.1
(67d)	A621	390	119	52	6.18	414	85	10.1	677	6	0.710	47.6
2/15/77	A111	121	36.9	1	0.0368	2.25	150	5.52	337	5	0.180	11.0
	A221	1,790	545	2	1.09	66.5	1	0.547	33.4	14	7.65	467
3/8/77	A321	1,290	393	2	0.787	48.0	150	59.1	3,610	24	9.45	576
	A411	1,400	427	3	1.28	78.1	40	17.1	1,040	5	2.14	130
4/17/77	A511	1,090	332	2	0.662	40.4	50	16.6	1,010	8	2.65	162
(61d)	A621	390	119	2	0.238	14.5	85	10.1	616	3	0.357	21.8
4/17/77	A111	121	36.9	2	0.074	4.88	110	4.05	267	11	0.405	26.7
	A221	1,790	545	2	1.09	71.9	1	0.547	36.1	26	14.2	937
5/16/77	A321	1,290	393	2	0.787	51.9	90	35.4	2,340	19	7.48	494
	A411	1,400	427	2	0.855	56.4	45	19.2	1,270	7	3.00	198
6/22/77	A511	1,090	332	2	0.663	43.8	55	18.2	1,200	10	3.31	219
(66d)	A521	390	119	2	0.240	15.8	85	10.1	667	13	1.55	102
6/22/77	A111	121	36.9	2	0.074	4.14	90	3.13	175	9	0.331	18.5
	A221	1,790	545	2	1.09	61.0	1	0.547	30.6	24	13.1	734
7/18/77	A321	1,290	393	2	0.787	44.1	65	25.6	1,430	26	10.2	571
	A411	1,400	427	2	0.855	47.9	40	17.1	958	4	1.71	95.7
8/17/77	A511	1,090	332	2	0.663	37.1	60	19.9	1,110	6	2.00	112
(56d)	A621	390	119	2	0.240	13.4	35	4.16	233	4	0.476	26.7
8/17/77	A111	121	36.9	2	0.074	1.63	65	2.39	52.6	4	0.147	3.23
	A221	1,790	545	2	1.09	24.0	1	0.547	12.0	23	12.6	277
	A321	1,290	393	2	0.787	17.3	65	25.6	563	21	8.27	182
9/9/77	A411	1,400	427	4	1.71	37.6	32	13.7	301	3	1.28	28.2
	A511	1,090	332	14	4.64	102	35	11.6	255	3	1.00	22
(22d)	A621	390	119	2	0.238	5.24	28	3.33	73.3	4	0.476	10.5
Sum 312.5d	$A_{v,\ in}$	6,080	1,850	--	41.6‡	13,000	--	125‡	39,100	--	45.4‡	14,200

TABLE 25. (Continued)

Period	Area symbol*	Soluble Fe			Soluble Hg			Soluble Pb			Soluble Zn		
		C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)
11/1/76	A111	0.30	0.011	0.446	0.0002	0.0000074	0.0003	0.005	0.00018	0.0073	0.07	0.0026	0.105
	A221	1.40	0.765	31.0	0.0002	0.0011	0.0450	0.005	0.0027	0.109	0.01	0.0055	0.223
	A321	5.90	2.32	94.0	0.0027	0.0011	0.0450	0.010	0.0039	0.158	0.08	0.0315	1.28
12/10/76	A411	120	51.3	2,080	0.0002	0.0012	0.0490	0.210	0.0898	3.64	1.10	0.470	19.0
	A511	83.0	27.5	1,110	0.0005	0.00016	0.0065	0.200	0.066	2.67	1.00	0.331	13.4
(40.5d)	A621	420	50.0	2,030	0.0002	0.00002	0.0008	0.100	0.012	0.486	1.20	0.143	5.8
12/10/76	A111	0.30	0.011	0.737	0.0002	0.0000074	0.0005	0.005	0.00018	0.012	0.07	0.0026	0.174
	A221	0.50	0.273	18.3	0.0010	0.0005	0.0335	0.008	0.0044	0.295	0.01	0.0055	0.369
1/20/77	A321	38.0	15.0	1,010	0.0002	0.000078	0.0053	0.043	0.0170	1.14	0.11	0.0433	2.90
	A411	3.30	1.41	765	0.0002	0.0012	0.080	0.009	0.0038	0.255	0.05	0.021	1.41
2/15/77	A511	0.30	0.099	6.63	0.0002	0.0000066	0.0004	0.005	0.0017	0.114	0.01	0.0033	0.220
(67d)	A621	6.60	0.785	52.6	0.0010	0.00012	0.0080	0.012	0.0014	0.094	0.19	0.0226	1.51
2/15/77	A111	4.60	0.169	10.3	0.0020	0.000074	0.0045	0.005	0.00018	0.011	0.03	0.0011	0.067
	A221	13.0	7.10	433	0.0030	0.0016	0.0980	0.005	0.0027	0.165	0.03	0.016	0.976
3/8/77	A321	61.0	24.0	1,460	0.0030	0.0011	0.0671	0.060	0.0240	1.46	0.37	0.0146	0.891
	A411	69.0	29.5	1,800	0.0010	0.0004	0.024	0.200	0.0855	5.22	0.62	0.265	16.2
4/17/77	A511	28.0	9.28	566	0.0010	0.0003	0.0180	0.100	0.033	2.01	0.21	0.070	4.27
(61d)	A621	44.0	5.23	319	0.0010	0.00012	0.0070	0.070	0.008	0.49	0.21	0.025	1.525
4/17/77	A111	8.20	0.302	19.9	0.0002	0.000007	0.0005	0.005	0.00018	0.0119	0.73	0.027	1.78
	A221	29.0	15.9	1,050	0.0006	0.00033	0.0220	0.005	0.0027	0.178	1.40	0.765	50.5
5/16/77	A321	284	112	7,390	0.0002	0.000079	0.0052	0.071	0.0279	1.84	1.20	0.472	31.2
	A411	125	53.4	3,520	0.0002	0.0012	0.0800	0.102	0.0453	3.00	0.56	0.239	15.8
6/22/77	A511	186	61.6	4,070	0.0002	0.000067	0.0044	0.207	0.0686	4.53	0.90	0.298	19.7
(66d)	A621	246	29.3	1,930	0.0003	0.000036	0.0024	0.083	0.0099	0.653	0.87	0.103	6.80
6/22/77	A111	8.90	0.328	18.4	0.0008	0.00003	0.0017	0.005	0.00018	0.010	0.07	0.0026	0.146
	A221	28.0	15.3	857	0.0002	0.0011	0.062	0.005	0.0027	0.151	0.03	0.016	0.900
7/18/77	A321	17.0	6.69	375	0.0002	0.000079	0.0040	0.005	0.0020	0.112	0.03	0.012	0.672
	A411	4.50	1.92	108	0.0002	0.0012	0.0670	0.005	0.0021	0.118	0.07	0.030	1.12
8/17/77	A511	59.0	19.5	1,090	0.0002	0.000066	0.0037	0.200	0.066	3.70	0.49	0.162	9.07
(56d)	A621	30.0	3.57	200	0.0004	0.000048	0.0027	0.028	0.0033	0.185	0.15	0.018	1.01
8/17/77	A111	7.00	0.258	5.68	0.0002	0.0000074	0.00016	0.005	0.00018	0.004	0.03	0.0011	0.024
	A221	32.0	17.5	385	0.0002	0.0011	0.0242	0.005	0.0027	0.060	0.04	0.022	0.484
	A321	49.0	19.3	425	0.0018	0.0007	0.0150	0.035	0.014	0.310	0.15	0.059	1.30
9/9/77	A411	2.30	0.984	20.9	0.0002	0.0012	0.0260	0.005	0.002	0.044	0.10	0.043	0.950
	A511	15.0	4.97	109	0.0002	0.000067	0.0015	0.005	0.0017	0.037	0.15	0.050	1.10
(22d)	A621	5.60	0.666	14.7	0.0002	0.00002	0.0004	0.048	0.0057	0.125	0.80	0.095	2.09
Sum 312.5d	$A_{v,\ in}$	--	107‡	33,400	--	0.0026‡	0.816	--	0.107‡	33.4	--	0.688‡	215

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* Area symbol A_{ijk}: where i = offsite well number; j = level of sampling point in well; and k = soil layer if k = 1 = lower clay and k = 2 = sand.

† Concentrations of constituents on 9/9/77 are from concentration versus time diagram (see Figures 48 to 54).

# Contaminant flux (J) = C (ppm) x Q (m^3/d) x 10^{-3} (unit = kg/d).

** Input mass (M) through vertical inlet section of the control volume = J x Period (unit = kg)

‡ Average value.

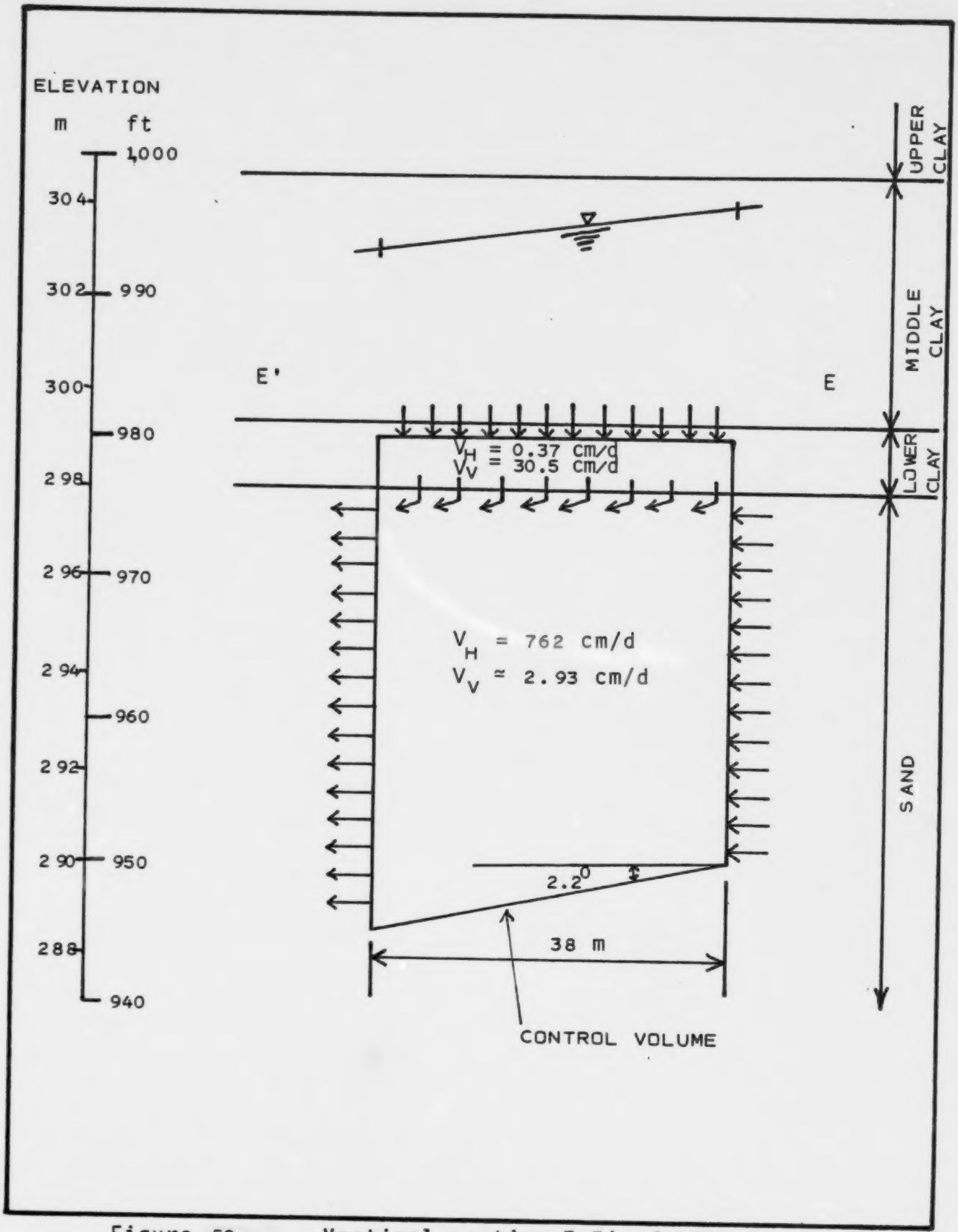
ELEVATION
m
ft
1,000
304
302
990
300
980
298
296
970
294
960
292
290
950
288
940
E'
E
V_H = 0.37 cm/d
V_V = 30.5 cm/d
V_H = 762 cm/d
V_V ≈ 2.93 cm/d
2.2°
38 m
CONTROL VOLUME
UPPER CLAY
MIDDLE CLAY
LOWER CLAY
SAND

Figure 59. Vertical section E-E' of site 3 (see Figure 47).

TABLE 26. CONTAMINANT FLUX AND MASS THROUGH HORIZONTAL INLET SECTION OF SITE 3 (SAND LAYER)

Period	Area symbol*	Area (m^2)	Q (m^3/d)	Cl⁻ C (ppm)†	Cl⁻ J (kg/d)‡	Cl⁻ M (kg)**	$SO_4^=$ C (ppm)	$SO_4^=$ J (kg/d)	$SO_4^=$ M (kg)	TOC C (ppm)	TOC J (kg/d)	TOC M (kg)
11/1/76	A122	94	716	99	71.0	2,900	240	172	6,970	114	81.8	3,310
	A132	69	525	74	38.9	1,600	160	84.2	3,410	55	26.9	1,170
	A142	58.5	445	115	51.3	2,080	160	71.4	2,890	55	24.5	992
12/10/76	A232	169	1,287	120	155	6,280	25	32.2	1,300	35	45.1	1,830
	A242	490	3,733	57	213	8,630	30	112	4,540	68	254	10,300
	A322	158	1,203	100	120	4,860	200	240	9,720	70	84.1	3,410
	A332	165	1,257	110	139	5,630	210	265	10,700	46	58.0	2,350
(40.5d)	A342	139	1,059	3,600	3,800	154,000	200	155	6,280	46	48.6	1,970
12/10/76	A122	94	716	96	68.9	4,620	225	161	10,800	42	30.1	2,020
	A132	69	525	98	51.6	3,460	160	84.2	5,640	9	4.73	317
1/20/77	A142	585	445	98	43.7	2,930	160	71.4	4,780	9	4.01	269
	A232	169	1,287	38	48.9	3,280	50	64.4	4,310	10	12.9	864
2/15/77	A242	490	3,733	58	216	14,500	45	168	11,300	11	41.0	2,750
	A322	158	1,203	140	168	11,300	180	216	14,500	61	73.3	4,910
	A332	165	1,257	94	119	7,970	160	202	13,500	26	32.8	2,210
(67d)	A342	139	1,059	142	150	10,100	100	106	7,100	30	31.7	2,120
2/15/77	A122	94	716	1	0.72	44	170	122	7,440	3	2.15	131
	A132	69	525	2	1.05	64.1	125	65.7	4,010	6	3.16	193
3/8/77	A142	58.5	445	2	0.89	54.3	125	55.8	3,400	6	2.68	163
	A232	169	1,287	2	2.58	157	30	38.6	2,360	16	20.6	1,260
4/17/77	A242	490	3,733	2	7.46	455	35	131	7,990	8	29.8	1,820
	A322	158	1,203	2	2.40	146	150	180	11,000	24	28.8	1,760
	A332	165	1,257	2	1.26	76.9	90	113	6,890	8	10.1	616
(61d)	A342	139	1,059	2	2.11	129.	90	95.0	5,800	8	8.44	515
4/17/77	A122	94	716	2	1.43	94.4	100	71.7	4,730	9	6.45	426
	A132	69	525	2	1.05	69.3	85	44.7	2,950	8	4.21	278
5/16/77	A142	58.5	445	2	0.890	58.7	85	37.9	2,500	8	3.57	236
	A232	169	1,287	2	2.58	170	110	142	9,370	7	9.01	595
6/22/77	A242	490	3,733	2	7.46	492	160	597	39,400	8	29.8	1,970
	A322	158	1,203	2	2.40	158	90	108	7,130	19	22.8	1,500
	A332	165	1,257	2	1.26	83.2	85	107	7,060	12	15.1	1,000
(66d)	A342	139	1,059	2	2.11	139	85	89.7	5,920	12	12.7	838
6/22/77	A122	94	716	2	1.43	80.1	125	89.6	5,020	8	5.73	321
	A132	69	525	2	1.05	58.8	70	36.8	2,060	3	1.58	88.5
7/18/77	A142	58.5	445	2	0.89	49.8	70	31.2	2,060	3	1.34	75.0
	A232	169	1,287	2	2.58	145	45	57.9	3,240	6	7.73	433
8/17/77	A242	490	3,733	2	7.46	418	45	168	9,410	5	18.6	1,040
	A322	158	1,203	2	2.40	134	65	78.1	4,370	26	31.2	1,750
	A332	165	1,257	2	1.26	70.6	65	82.0	4,600	7	8.83	495
(56d)	A342	139	1,059	2	2.11	118	65	68.6	3,840	7	7.39	414
8/17/77	A122	94	716	2	1.43	29.3	102	73.1	1,500	4	2.87	58.8
	A132	69	525	2	1.05	21.5	58	30.5	625	4	2.10	43.1
	A142	58.5	445	2	0.89	18.2	58	28.9	592	4	1.78	36.5
9/7/77	A232	169	1,287	2	2.58	52.9	108	139	2,850	4	5.15	288
	A242	490	3,733	2	7.46	153	45	168	3,440	5	18.6	1,040
	A322	158	1,203	2	2.40	49.2	65	78.1	1,600	21	25.2	517
	A332	165	1,257	2	1.26	25.8	71	89.5	1,840	5.5	6.93	142
	A342	139	1,059	2	2.11	43.3	71	74.9	1,540	5.5	5.81	120
Sum - 311d	A_H, in	1,340	10,220	—	797‡	248,000.	—	1,170†	364,000.	—	196‡	61.000

TABLE 26 (Continued)

Period	Area symbol*	Soluble Fe C (ppm)	Soluble Fe J (kg/d)	Soluble Fe M (kg)	Soluble Hg C (ppm)	Soluble Hg J (kg/d)	Soluble Hg M (kg)	Soluble Pb C (ppm)	Soluble Pb J (kg/d)	Soluble Pb M (kg)	Soluble Zn C (ppm)	Soluble Zn J (kg/d)	Soluble Zn M (kg)
11/1/76	A122	2.90	2.08	84.2	0.0002	0.00014	0.0057	0.005	0.0036	0.150	0.01	0.007	0.280
	A132	140	73.6	2,980	0.0002	0.0001	0.0041	0.14	0.0737	3.00	1.70	0.894	36.2
	A142	44.0	19.6	794	0.0005	0.0002	0.0081	0.17	0.0758	3.10	0.54	0.241	9.76
	A232	0.03	0.04	1.62	0.0004	0.0005	0.020	0.005	0.0064	0.260	0.01	0.013	0.53
12/10/76	A242	0.10	0.37	15.0	0.0002	0.0007	0.028	0.005	0.0187	0.760	0.01	0.037	1.50
	A322	5.90	7.10	287	0.0027	0.0032	0.130	0.010	0.0120	0.490	0.08	0.096	3.90
	A332	0.50	0.63	25.5	0.0002	0.0002	0.008	0.005	0.0063	0.260	0.05	0.063	2.55
(40.5d)	A342	0.50	0.53	21.5	0.0002	0.0002	0.008	0.005	0.0053	0.210	0.05	0.053	2.15
12/10/76	A122	120	86.1	5,770	0.0002	0.0001	0.0067	0.074	0.0530	3.55	0.85	0.610	41.0
	A132	27.0	14.2	951	0.0020	0.0010	0.057	0.054	0.0280	1.88	0.12	0.063	4.22
1/20/77	A142	27.0	12.0	804	0.0020	0.0009	0.060	0.054	0.0240	1.61	0.12	0.054	3.62
	A232	3.70	4.76	319	0.0009	0.0012	0.080	0.005	0.0064	0.43	0.03	0.039	2.61
2/15/77	A242	5.50	20.5	1,370	0.0003	0.0011	0.074	0.005	0.0187	1.25	0.01	0.037	2.48
	A322	38.0	42.7	2,860	0.0002	0.0002	0.013	0.043	0.0520	3.50	0.11	0.132	8.85
	A332	270	340	22,800	0.0002	0.0002	0.013	0.005	0.0060	0.410	0.77	0.971	65.1
(67d)	A342	160	169	11,300	0.0002	0.0002	0.013	0.005	0.0053	0.360	0.43	0.454	30.4
2/15/77	A122	16.0	11.5	701	0.0020	0.0014	0.085	0.040	0.0287	1.75	0.15	0.110	6.70
	A132	6.40	3.37	206	0.0030	0.0016	0.098	0.007	0.0037	0.230	0.04	0.021	1.28
3/8/77	A142	6.40	2.85	174	0.0030	0.0013	0.080	0.007	0.0031	0.190	0.04	0.018	1.10
	A232	180	232	14,200	0.0030	0.0039	0.240	0.014	0.0180	1.10	0.92	1.18	72.0
4/17/77	A242	9.20	34.3	2,090	0.0030	0.0112	0.680	0.007	0.0260	1.60	0.10	0.373	22.7
	A322	61.0	73.3	4,470	0.0030	0.004	0.244	0.060	0.0720	4.4	0.37	0.444	27.1
	A332	220	277	16,900	0.0030	0.0038	0.232	0.020	0.0250	1.53	0.38	0.479	29.2
(61d)	A342	220	232	14,200	0.0030	0.0032	0.195	0.020	0.0210	1.30	0.38	0.401	24.5
4/17/77	A122	176	126	8,320	0.0005	0.0036	0.024	0.172	0.123	8.10	1.40	1.00	66.0
	A132	152	80.0	5,280	0.0003	0.00016	0.011	0.061	0.0320	2.10	0.73	0.384	25.3
5/16/77	A142	152	67.8	4,480	0.0003	0.00013	0.009	0.061	0.0270	1.80	0.73	0.326	21.5
	A232	88.0	113	7,460	0.0002	0.00026	0.017	0.025	0.0320	2.10	0.62	0.798	52.7
6/22/77	A242	35.0	123	8,120	0.0002	0.00075	0.0495	0.010	0.0370	2.40	0.26	0.970	64.0
	A322	284	341	22,500	0.0002	0.00024	0.016	0.071	0.0850	5.60	1.20	1.44	95.0
	A332	291	367	24,200	0.0002	0.00025	0.016	0.082	0.103	6.80	1.60	2.02	133
(66d)	A342	291	307	20,300	0.0002	0.00021	0.014	0.082	0.0870	5.70	1.60	1.69	111
6/22/77	A122	7.60	5.45	305	0.0002	0.0001	0.0056	0.068	0.0490	2.70	0.03	0.022	1.23
	A132	32.0	16.8	941	0.0002	0.0001	0.0056	0.007	0.0037	0.210	0.17	0.089	4.98
7/18/77	A142	32.0	14.3	800	0.0002	0.00009	0.005	0.007	0.0031	0.170	0.17	0.076	4.26
	A232	15.0	6.70	375	0.0002	0.00026	0.015	0.007	0.0090	0.500	0.08	0.103	5.80
8/17/77	A242	4.70	17.5	980	0.0002	0.00075	0.042	0.005	0.0190	1.06	0.01	0.037	2.10
	A322	17.0	20.4	1,140	0.0002	0.0002	0.011	0.005	0.0060	0.340	0.03	0.036	2.02
	A332	231	291	16,300	0.0002	0.00025	0.014	0.200	0.252	14.1	1.00	1.26	70.6
(56d)	A342	231	244	13,700	0.0002	0.00021	0.012	0.200	0.211	11.8	1.00	1.06	59.4
8/17/77	A122	7.00	5.02	103	0.0002	0.0001	0.002	0.015	0.0110	0.230	0.08	0.057	1.17
	A132	10.0	5.26	108	0.0002	0.0001	0.002	0.004	0.0020	0.040	0.05	0.026	0.533
	A142	10.0	4.46	91.4	0.0002	0.00009	0.0018	0.004	0.0018	0.040	0.05	0.022	0.451
9/7/77	A232	5.00	6.44	132	0.0002	0.00026	0.0053	0.005	0.0064	0.130	0.03	0.039	0.800
	A242	2.00	7.46	153	0.0024	0.009	0.185	0.005	0.0187	0.380	0.04	0.149	3.05
	A322	37.2	44.7	916	0.0018	0.0022	0.045	0.030	0.0360	0.740	0.15	0.180	3.70
	A332	49.0	61.8	1,270	0.0002	0.00025	0.005	0.040	0.0500	1.03	0.24	0.303	6.21
(20.5d)	A342	49.0	51.7	1,080	0.0002	0.00021	0.004	0.040	0.0420	0.870	0.24	0.253	5.19
Sum - 311d	A_{11}, in	—	781‡	243,000.	—	0.0093‡	2.90	—	0.328‡	102	—	3.67‡	1,140

* Area symbol A_{ijk}: where i = offsite well number; j = level of sampling point in well; and k = soil layer if k = 1 = lower clay and k = 2 = sand.

† Concentrations of constituents on 9/7/77 are from concentration versus time diagram (see Figures 48 to 54).

‡ Contaminant flux (J) = C (ppm) x Q (m^3/d) x 10^{-3} (unit = kg/d).

** Input mass (M) through vertical inlet section of the control volume = J x Period (unit = kg).

TABLE 27. CONTAMINANT FLUX AND MASS THROUGH HORIZONTAL OUTLET SECTION OF SITE 3 (SAND LAYER)

Period	Area symbol*	Area (m^2)	Q (m^3/d)	Cl⁻ C (ppm)†	Cl⁻ J (kg/d)#	Cl⁻ M (kg)**	$SO_4^=$ C (ppm)	$SO_4^=$ J (kg/d)	$SO_4^=$ M (kg)	TOC C (ppm)	TOC J (kg/d)	TOC M (kg)
11/6/76	A412	40	304	93	28.3	991	135	38.0	1,330	32	9.71	340
	A422	181	1,378	56	77.3	2,710	105	145	5,080	29	40.0	1,400
	A432	163	1,241	96	119	4,160	138	172	6,020	155	192	6,720
	A442	183	1,393	87	121	4,240	130	181	6,340	13	18.1	634
	A512	30.9	234	92	217	7,600	129	30.4	1,060	13	3.06	107.1
	A522	221	1,683	92	155	5,430	129	217	7,600	13	21.8	763
	A532	254	1,934	98	190	6,650	128	248	8,680	131	253	8,860
	A542	185	1,409	33	46.6	1,630	80	113	3,960	170	240	8,400
	A622	81.6	621	60	37.3	1,310	80	49.7	1,740	30	18.6	651
12/10/87	A632	105	800	89	71.0	2,490	151	120	4,200	96	76.4	2,670
(35d)	A642	141	1,073	83	89.3	3,126	129	139	4,860	9	9.67	339
12/10/76	A412	40	304	27	8.2	549	50	15.2	1,018	6	1.82	122
	A422	181	1,378	33	45.6	3,060	60	82.8	5,550	8	11.0	7,440
	A432	163	1,241	119	148	9,912	115	143	9,580	3	3.72	249
	A442	183	1,393	94	131	8,780	165	230	15,400	4	5.57	373
2/15/77	A512	30.9	234	82	19.3	1,290	115	27.1	1,820	1	.235	15.7
	A522	221	1,683	86	145	9,720	125	210	14,100	5	8.40	563
	A532	254	1,934	126	244	16,300	110	212	14,200	2	3.86	259
	A542	185	1,409	24	33.9	2,270	75	105	7,040	2	2.82	189
	A622	81.6	621	52	32.3	2,160	85	52.8	3,540	6	3.72	249
2/15/77	A632	105	800	83	66.1	4,430	160	127	8,510	6	4.77	320
(67d)	A642	141	1,073	79	85.0	5,700	125	134	8,980	7	7.52	504
2/15/77	A412	40	304	3	0.910	55.5	40	12.1	738	5	1.51	92
	A422	181	1,378	4	5.52	337	50	69.0	4,210	6	8.28	505
	A432	163	1,241	3	3.73	228	75	93.1	5,680	8	9.94	606
	A442	183	1,393	3	4.18	255	75	104	6,340	8	11.1	677
3/8/77	A512	30.9	234	2	0.470	28.7	50	11.7	714	6	1.88	115
	A522	221	1,683	69	116	7,080	137	230	14,000	6	10.0	610
	A532	254	1,934	66	128	7,810	115	222	13,500	4	7.73	472
	A542	185	1,409	2	2.82	172	50	70.6	4,310	4	5.64	344
	A622	81.6	64	2	1.24	75.6	85	52.8	3,220	3	1.86	113
4/17/77	A632	105	800	8	6.37	389	140	111	6,770	2	1.59	97.0
(61d)	A642	141	1,073	4	4.30	262	85	91.4	5,580	5	5.37	328
4/17/77	A412	40	304	2	0.610	40.3	45	13.6	898	7	2.17	140
	A422	181	1,378	2	2.76	182	45	62.1	4,100	6	8.28	547
	A432	163	1,241	2	2.49	164	50	62.1	4,100	7	8.69	574
	A442	183	1,393	2	2.79	184	50	69.7	4,600	7	9.76	644
5/16/77	A512	30.9	234	2	0.47	31.0	55	12.9	851	10	2.35	155
	A522	221	1,683	51	85.8	5,660	150	252	16,600	7	11.7	772
	A532	254	1,934	20	38.7	2,550	65	125	8,250	7	13.5	891
	A542	185	1,409	2	2.82	186	40	56.4	3,720	9	12.7	838
	A622	81.6	621	2	1.24	81.8	85	52.8	3,480	13	8.08	533
6/22/77	A632	105	800	2	1.60	106	105	83.6	3,540	9	7.16	473
(66d)	A642	141	1,073	2	2.15	142	100	107	7,060	12	12.9	851

TABLE 27 (Continued)

Period	Area symbol	Soluble Fe			Soluble Hg			Soluble Pb			Soluble Zn		
		C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)
11/6/76	A412	118	35.8	1,250	0.0002	0.000061	0.0021	0.210	0.064	2.24	1.00	0.303	10.6
	A422	119	164	5,740	0.0002	0.00028	0.0098	0.190	0.262	9.17	0.780	1.07	37.5
	A432	141	175	6,130	0.0002	0.00025	0.0088	0.010	0.0124	0.434	0.900	1.11	38.9
	A442	1.50	2.09	73.2	0.0002	0.00028	0.0098	0.005	0.007	0.245	0.010	0.014	0.490
	A512	82.0	19.3	676	0.0005	0.000012	0.00042	0.200	0.047	1.65	0.980	0.231	8.09
12/10/76	A522	229	385	13,500	0.0002	0.00034	0.012	0.400	0.672	23.5	1.08	1.82	63.7
	A532	80.0	154	5,390	0.0002	0.00039	0.014	0.100	0.193	6.76	0.870	1.68	58.8
	A542	104	146	5,110	0.0010	0.0014	0.049	0.210	0.296	10.4	0.950	1.34	46.9
	A622	416	258	9,030	0.0002	0.00012	0.0042	0.100	0.062	2.17	1.18	0.733	25.7
	A632	13.0	10.3	361	0.0002	0.00016	0.0056	0.040	0.032	1.12	0.140	0.111	3.89
(35d)	A642	25.0	26.8	938	0.0002	0.00022	0.0077	0.059	0.063	2.21	0.220	0.236	8.26
12/10/76	A412	3.30	1.00	67.0	0.0002	0.000061	0.0041	0.009	0.0027	0.181	0.050	0.015	1.01
	A422	66.0	91.1	6,100	0.0002	0.00028	0.019	0.080	0.110	7.37	0.220	0.303	20.3
	A432	160	198	13,300	0.0002	0.00025	0.017	0.014	0.017	1.14	0.570	0.708	47.4
1/20/77	A442	0.01	.013	0.870	0.0002	0.00028	0.019	0.005	0.007	0.47	0.010	0.014	0.940
	A512	0.03	.007	0.470	0.0002	0.000047	0.003	0.005	0.0011	0.74	0.010	0.0025	0.170
	A522	82.0	137	9,180	0.0002	0.00034	0.023	0.160	0.269	18.0	0.700	1.17	78.4
2/15/77	A532	40.0	77.3	5,180	0.0002	0.00039	0.026	0.160	0.309	20.7	0.280	0.541	36.2
	A542	60.0	84.7	5,670	0.0002	0.00028	0.019	0.190	0.268	18.0	0.710	1.00	67.0
	A622	6.60	4.10	275	0.0010	0.00062	0.042	0.012	0.0074	0.500	0.190	0.118	7.90
	A632	16.0	12.7	851	0.0002	0.00016	0.011	0.039	0.031	2.08	0.170	0.135	9.05
(67d)	A642	1.40	1.50	101	0.0007	0.00075	0.050	0.005	0.0054	0.360	0.020	0.022	1.47
2/15/77	A412	69.0	20.9	1,280	0.0010	0.00030	0.0183	0.200	0.061	3.72	0.620	0.188	11.5
	A422	5.30	7.31	446	0.0010	0.0014	0.085	0.008	0.011	0.670	0.070	0.100	6.10
	A432	23.0	28.5	1,740	0.0010	0.0012	0.073	0.050	0.062	3.78	0.170	0.211	12.9
3/8/77	A442	23.0	32.0	1,950	0.0010	0.0014	0.085	0.050	0.070	4.27	0.170	0.237	14.6
	A512	28.0	6.60	403	0.0010	0.00024	0.015	0.100	0.023	1.40	0.210	0.050	3.10
	A522	158	265	16,170	0.0004	0.00067	0.041	0.300	0.504	30.7	1.00	1.68	102
4/17/77	A532	0.02	.038	2.32	0.0002	0.00039	0.024	0.005	0.0097	0.592	0.020	0.040	2.44
	A542	110	155	9,460	0.0002	0.00028	0.017	0.400	0.564	34.4	1.10	1.55	94.6
	A622	44.0	27.3	1,670	0.0010	0.00061	0.037	0.070	0.044	2.68	0.21	0.130	7.93
	A632	85.0	67.7	4,130	0.0005	0.0004	0.024	0.070	0.056	3.42	0.63	0.501	30.6
(61d)	A642	2.50	2.68	163	0.0010	0.0011	0.671	0.005	0.054	3.29	0.04	.043	2.62
4/17/77	A412	125	37.9	2,500	0.0002	0.000061	0.004	0.102	0.031	2.05	0.560	0.170	11.2
	A422	109	150	9,900	0.0002	0.00028	0.018	0.135	0.186	12.3	0.550	0.759	50.1
	A432	203	252	16,600	0.0003	0.00037	0.024	0.227	0.282	18.6	1.10	1.36	89.8
5/16/77	A442	203	283	18,700	0.0003	0.00042	0.028	0.227	0.316	20.9	1.10	1.53	101
	A512	186	43.8	2,890	0.0002	0.00047	0.031	0.207	0.049	3.23	0.900	0.212	14.0
	A522	275	462	3,050	0.0006	0.001	0.066	0.590	0.992	65.5	2.10	3.53	233
6/22/77	A532	144	278	18,300	0.0004	0.00077	0.051	0.100	0.193	12.7	0.910	1.75	116
	A542	81.0	114	7,520	0.0003	0.00042	0.028	0.001	0.0014	0.092	0.310	0.437	28.8
	A622	246	152	10,000	0.0003	0.00019	0.013	0.083	0.052	3.43	0.870	0.540	35.6
	A632	106	84.4	5,570	0.0003	0.00024	0.016	0.100	0.080	5.28	1.30	1.03	68.0
(66d)	A642	186	200	13,200	0.0002	0.00022	0.015	0.100	0.107	7.06	0.910	0.978	64.5

TABLE 27. (Continued)

Period	Area symbol	Area (m^2)	Q (m^3/d)	Cl^-			$SO_4^=$			TOC		
				C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)
6/22/77	A412	40	304	2	0.610	34.2	40	12.2	683	4	1.21	67.8
	A422	181	1,378	2	2.76	155	35	48.3	2,700	3	4.14	232
	A432	163	1,241	2	2.49	139	50	62.1	3,480	6	7.46	418
7/18/77	A442	183	1,393	2	2.79	156	50	69.7	3,900	6	8.37	469
	A512	30.9	234	2	0.470	26.3	60	14.1	790	6	1.41	79.0
	A522	221	1,683	39	65.6	3,670	100	168.0	9,410	5	8.41	471
8/17/77	A532	254	1,934	7	13.5	756	40	77.3	4,330	4	7.73	433
	A542	185	1,409	2	2.82	158	4	5.65	316	5	7.06	396
	A622	81.6	621	2	1.24	69.4	35	21.7	1,220	4	2.49	139
	A632	105	800	2	1.60	89.6	85	67.7	3,790	4	3.19	179
(56d)	A642	141	1,073	3.1	3.33	187	85	91.4	5,120	6	6.45	361
8/17/77	A412	40	304	4	1.21	31.7	30	9.11	239	3	0.911	23.9
	A422	181	1,378	4	5.52	145	30	41.4	1,086	2	2.76	72.4
	A432	163	1,241	2	2.49	65.3	35	43.5	1,140	2	2.49	65.3
9/12/77	A442	183	1,393	2	2.79	73.2	35	48.8	1,280	2	2.79	73.2
	A512	30.9	234	15	3.54	92.9	33	7.78	204	3	0.707	18.5
	A522	221	1,683	27	45.4	1,190	55	92.5	2,430	3	5.04	132
	A532	254	1,934	12	23.2	610	34	65.7	1,720	3	5.80	152
	A542	185	1,409	5	7.06	186	17	24.0	630	4	5.65	148
	A622	81.6	621	2	1.24	32.5	40	25.0	656	4	2.50	65.6
	A632	105	800	2	1.60	42.0	61	48.6	1,270	3	2.39	62.7
(26.23d)	A642	141	1,073	2	2.15	56.4	66	71.0	1,860	5	5.38	141
Sum - 311.23d	$A_{h, out}$	1,580	12,070	—	447‡	139,000	—	999‡	311,000	–	179‡	55,700

TABLE 27 (Continued)

		Soluble Fe			Soluble Hg			Soluble Pb			Soluble Zn		
Period	Area Symbol*	C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)	C (ppm)	J (kg/d)	M (kg)
6/22/77	A412	4.50	1.37	76.7	0.0002	0.000061	0.003	0.005	0.0015	0.084	0.07	0.021	1.18
	A422	36.0	49.7	2,780	0.0002	0.00028	0.016	0.082	0.113	6.33	0.20	0.280	15.7
	A432	96.0	119	6,660	0.0002	0.00025	0.014	0.230	0.286	16.0	0.53	0.660	37.0
	A442	96.0	134	7,500	0.0002	0.00028	0.016	0.230	0.321	18.0	0.53	0.740	41.4
7/18/77	A512	59.0	13.9	778	0.0002	0.00005	0.003	0.200	0.047	2.63	0.49	0.120	6.72
	A522	347	583	32,600	0.0007	0.0012	0.067	0.720	1.21	67.8	2.40	4.04	226
	A532	56.0	108	6,050	0.0005	0.0010	0.056	0.200	0.387	21.7	0.64	1.24	69.4
	A542	258	364	20,400	0.0004	0.0006	0.034	0.140	0.200	11.2	1.20	1.69	94.6
	A622	30.0	18.6	1,040	0.0004	0.0002	0.011	0.028	0.017	0.950	0.15	0.090	5.04
8/17/77	A632	80.0	63.7	3,570	0.0005	0.0004	0.022	0.420	0.335	18.8	1.70	1.35	75.6
(56d)	A642	210	226	12,700	0.0005	0.0005	0.028	0.200	0.215	12.0	1.00	1.07	60.0
8/17/77	A412	2.20	0.670	17.6	0.0002	0.000061	0.0016	0.005	0.0015	0.040	0.10	0.030	0.780
	A422	3.90	5.38	141	0.0002	0.00028	0.0073	0.005	0.007	0.180	0.14	0.190	4.98
	A432	5.60	6.96	183	0.0002	0.00025	0.0066	0.005	0.006	0.160	0.09	0.110	2.88
	A442	5.60	7.81	205	0.0002	0.00028	0.0073	0.005	0.007	0.180	0.09	0.126	3.30
	A512	11.0	2.59	68.0	0.0002	0.00005	0.0013	0.031	0.236	6.19	0.08	0.190	4.98
	A522	279	469	12,300	0.0018	0.003	0.079	0.850	1.43	37.5	1.60	2.69	70.6
	A532	78.0	151	3,960	0.0002	0.0004	0.011	0.450	0.870	22.8	0.95	2.88	75.5
	A542	114	161	4,220	0.0002	0.0003	0.008	0.460	0.650	17.0	0.85	1.20	31.5
	A622	264	164	4,300	0.0002	0.0001	0.003	0.510	0.320	8.40	0.86	0.53	13.9
9/12/77	A632	90.0	71.7	1,880	0.0002	0.00016	0.004	0.260	0.210	5.50	3.20	2.55	66.9
(26.23d)	A642	111	119	3,120	0.0022	0.0024	0.063	0.290	0.310	8.31	0.44	0.47	12.3
311.23d	$A_{h,\ out}$	--	1,260‡	39,1000	--	0.0063‡	1.96	--	2.22‡	690	--	9.64‡	3000

* Area symbol A_{ijk}: where i = offsite well number; j = level of sampling point in well; and k = soil layer if k = 1 = lower clay and k = 2 = sand.

† Concentrations of constituents on 11/6/76 are from concentration versus time diagram (see Figures 48 to 54).

# Contaminant flux (J) = C (ppm) x Q (m^3/d) x 10^{-3} (unit = kg/d).

** Input mass (M) through vertical output section of the control volume = J x Period (unit = kg).

‡ Average value.

The vertical flow in the sand formation of the control volume is derived from the following equation:

$$V_v = V_H \tan \theta \qquad (55)$$

$$= 762 \text{ cm/day} \times 0.038 = 29 \text{ cm/day (Figure 59)}$$

The revised shapes and subareas of the horizontal inlet and outlet planes were formed based on these calculations, and the flow rate passing through each subarea was then calculated. Results are given in Tables 26 and 27 and Figures 60 and 61.

Mass Balance--

The fluxes of the specific contaminants, J (kg/day), through the partitioned faces of the control volume were calculated using Equations 43 or 46. The input fluxes through the vertical lower clay layer and horizontal sand layer for each constituent were calculated; the results were given earlier in Tables 25 and 26, respectively. The horizontal output fluxes through the sand layer are given in Table 27.

Travel time for the vertical flow through the sand layer was about five days (38 ÷ 7.62 m/day ≈ 5 days); through the lower clay layer was about 3.5 days. This latter flow joined with the flow in the sand layer, and the total flow required 3.5 to 8.5 days to pass through the control volume. Based on the above information and the flow pattern, T_p and T_p' (inflow and outflow time periods, as defined in Section 5) values are as follows:

T_p for the inflow in sand layer = 311 days

T_p for the inflow in lower clay layer = 312.5 days

$$\text{Total input volume} = 311 \text{ d} \times 10{,}220 \text{ m}^3\text{/day} + 312.5 \text{ d} \times 1{,}850 \text{ m}^3\text{/day} = 3{,}756{,}545 \text{ m}^3$$

$$\text{So, } T_{p'} = \frac{3{,}756{,}545 \text{ m}^3}{12{,}070 \text{ m}^3\text{/day}} = 311.23 \text{ days.}$$

From the T_p and T_p' values, the total input and output mass of the control volume was solved; the results are given in Tables 22 to 24. The amount of contaminant flux and attenuation or elution of a certain contaminant was calculated using Equations 38 to 40 and 43 and 44. The results are tabulated below:

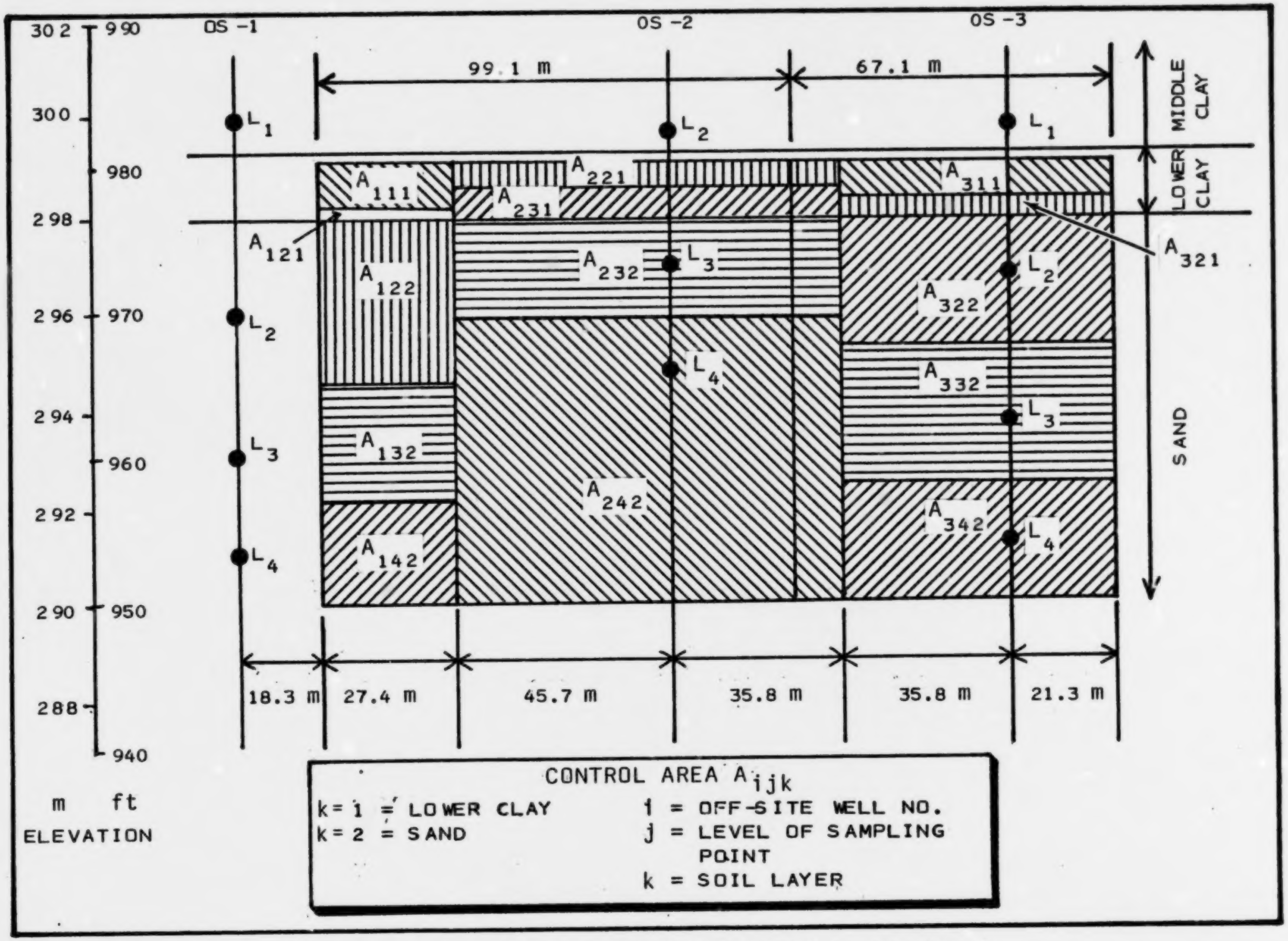
OS -1
OS -2
OS -3
99.1 m
67.1 m
L1
L2
L3
L4
A111
A121
A122
A132
A142
A221
A231
A232
A242
A311
A321
A322
A332
A342
MIDDLE CLAY
LOWER CLAY
SAND
302
300
298
296
294
292
290
288
990
980
970
960
950
940
m
ft
ELEVATION
18.3 m
27.4 m
45.7 m
35.8 m
35.8 m
21.3 m
CONTROL AREA A ijk
k= 1 = LOWER CLAY
k= 2 = SAND
i = OFF-SITE WELL NO.
j = LEVEL OF SAMPLING POINT
k = SOIL LAYER

Figure 60. Horizontal inlet section of site 3.

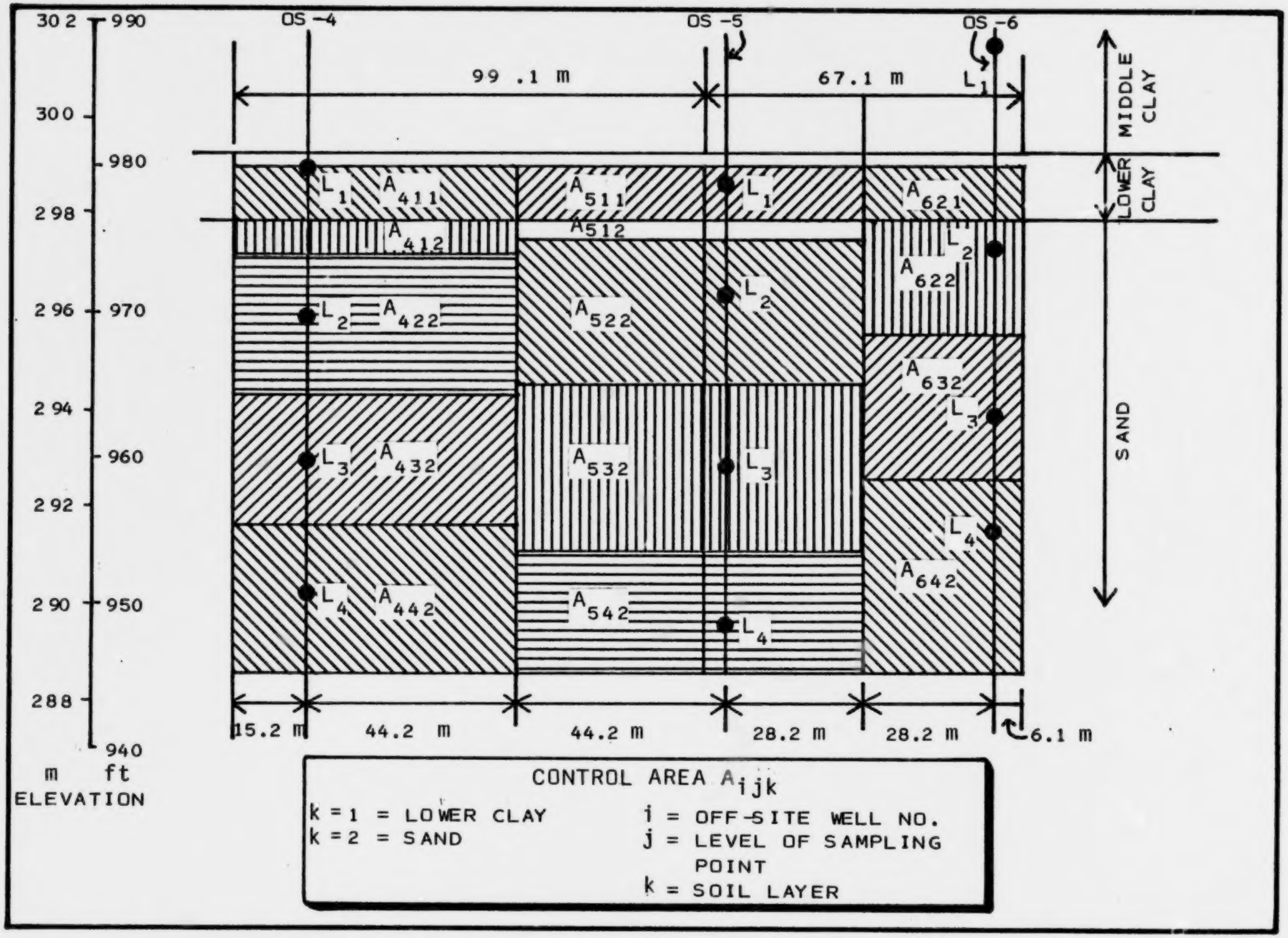
OS-4
OS-5
OS-6
99 .1 m
67.1 m
MIDDLE CLAY
LOWER CLAY
SAND
L_1
L_2
L_3
L_4
A_{411}
A_{412}
A_{422}
A_{432}
A_{442}
A_{511}
A_{512}
A_{522}
A_{532}
A_{542}
A_{621}
A_{622}
A_{632}
A_{642}
15.2 m
44.2 m
44.2 m
28.2 m
28.2 m
6.1 m
302
300
298
296
294
292
290
288
990
980
970
960
950
940
m
ft
ELEVATION
CONTROL AREA A_{ijk}
k = 1 = LOWER CLAY
k = 2 = SAND
i = OFF-SITE WELL NO.
j = LEVEL OF SAMPLING POINT
k = SOIL LAYER

Figure 61. Horizontal outlet section of site 3.

	Unit Input Flux		Unit Output Flux	
	Sand Layer	Lower Clay Layer	Sand Layer	Difference
	g/day/m^2			
Cl^-	595	7	283	319
SO_4^{2-}	873	21	632	262
TOC	146	7	113	40
Hg	0.0069	0.0004	0.0040	0.0033
Pb	0.245	0.018	1.41	-1.15
Zn	2.74	0.11	6.10	-3.25
Fe	583	17	797	-197

It is apparent that the sand layer transported more contaminants than the lower clay layer. Ratios of contaminant flux between sand and lower clay layers are listed below:

Contaminant	Ratio of Contaminant Flux $(\frac{\text{sand}}{\text{lower clay}})$
Cl^-	85
SO_4^{2-}	42
TOC	21
Hg	17
Pb	14
Zn	25
Fe	34

High groundwater flow is probably responsible in part for the high contaminant fluxes in the sand layer. However, the ratio of flow velocity between the sand and lower clay layers was about 25. Only the contaminant flux ratios of zinc and TOC were close to this velocity ratio, the others varied. Chloride, sulfate, and iron were higher, mercury and lead, lower. This could come from factors such as the difference of adsorption capacity or groundwater quality between the sand and the lower clay.

The quantity of contaminants attenuated or eluted can also be calculated; results are given below:

Contaminant	Attenuation mg/day/m^3	Elution mg/day/m^3	Percent Change
Cl^-	6,240		47
SO_4^{2-}	4,690		23
TOC	990		26
Hg	.0894		47
Pb		28.5	412
Zn		84.6	122
Fe		6,000	43

(Results are based on a 62,800-m^3 control volume.)

The data presented show that, with the exception of sulfate, iron, and mercury, the migration trends were similar to those for the Site 1 control volume. Chloride, sulfate, TOC, and soluble mercury were attenuated while soluble lead, zinc, and iron were eluted. The chloride attenuation seems much higher than theoretically possible. A probable source of this chloride was the salt used for road deicing. This salt entered the control volume as slugs of high concentrations during the winter, but had not yet passed out of the discharge end. These high chloride values distorted the mass balance calculations.

As previously suggested, the attenuation of mercury was probably due to the low solubilities and strong adsorption and complexation abilities of mercuric solids. The elution of iron from the soil could mean that the original groundwater and landfill leachate mixture was relatively reduced compared to the groundwater quality or that soluble iron complexes were formed during migration. The relatively high flow velocity at this site, about eight times higher than that at Site 1, also could account for the leaching or actual physical transport of some loosely adsorbed iron or iron colloids into the groundwater. The latter could also occur to lead and zinc. Because of the incomplete information on groundwater conditions, dissolved oxygen, sulfides, and other ligands, a detailed evaluation of the migration of iron, sulfate, lead, and zinc cannot be accurately assessed.

Site 3 had much higher contaminant fluxes than Site 1. The following is suggested:

- The higher unit groundwater flow rate at Site 3 could physically transport more constituents through the soil pore space.

- Site 3 is older and has been more heavily loaded. Although the sludge was placed within the clay strata at Site 3, the Site 3 soil seems to be completely saturated and the relatively higher amounts and concentrations of contaminants being leached into the groundwater reflect this slow but steady passage of contaminants.

- Since Site 3 has higner precipitation, rain, and snow than Site 1, more contaminants could be leached from the sludge at Site 3, assuming a direct correlation between contaminant transport and leachate generation.

Observations on Concentration Isopleths and Related Factors

As illustrated in Figure 3, the six new off-site plume wells were placed in two parallel lines, 73 m apart, south and southwest of the disposal area and across the path of the leachate plume and groundwater flows. Wells 1, 2, and 3 were in Line 1 and Wells 4, 5, and 6 were in Line 2. Due to a planned burial of additional sludge and inert debris, well placement was constrained to a narrow 46- to 75-m-wide zone between the disposal area and the two creeks to the south and west.

Concentration isopleths were prepared for the contaminants over the 1-yr sampling period (Figures 62 to 73). The geologic formations consisted of an upper unsaturated clay, middle saturated gumbo clay, and sand strata (6). Based on these isopleths, changes in concentration of a specific contaminant could be considered with regard to sampling location, depths, geohydrologic conditions, and season.

Site 3 is located in a temperate zone of the continental United States and is subjected to rather sharp demarcations in season and climate. These climatic changes strongly influenced the observed concentration trends for various contaminants. The soil surface was frozen and covered with snow in the severe winter of 1976-1977. The amount of infiltration or groundwater flow was minimal, as shown by specific conductance isopleths (Figure 73). The extreme stratification ranging from the top 10,000 to 2,500 mhos/cm in about 3 m is quite interesting. Under these conditions, the leachate plumes observed for the various contaminants were distinct entities and usually were associated with one particular soil stratum. Thus, the leachate plumes were moving at a predictable rate within that particular soil stratum and emerging across the monitoring boundaries. The winter months would, therefore, appear to be an ideal time to determine the actual concentration gardients of certain contaminants within a particular soil stratum. Overall, the leachate plumes varied significantly with sampling time; it was present at one particular point in the monitoring grid during one sampling and was almost completely

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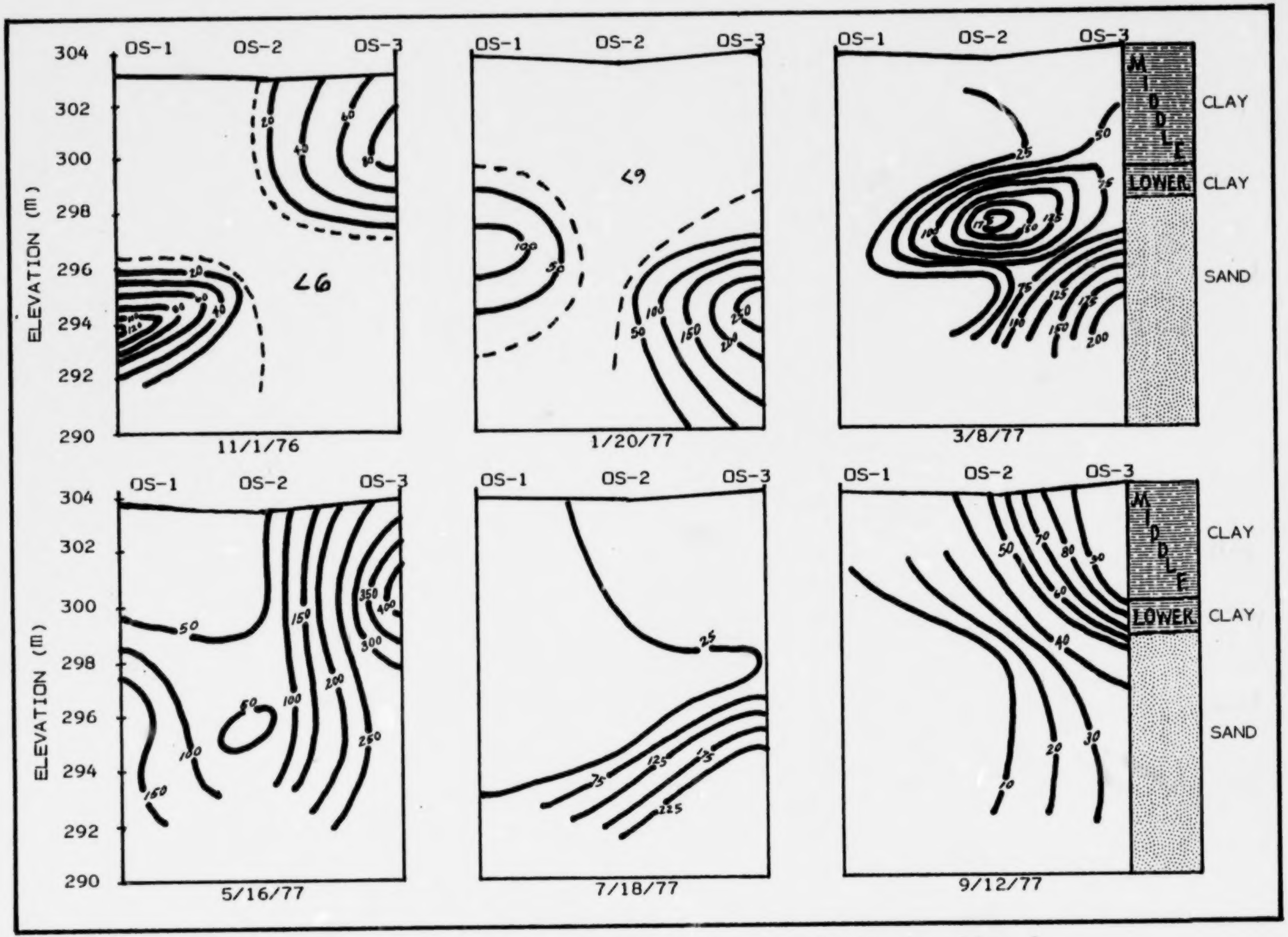

Figure 62a. Site 3 iron concentration isopleths for line 1.

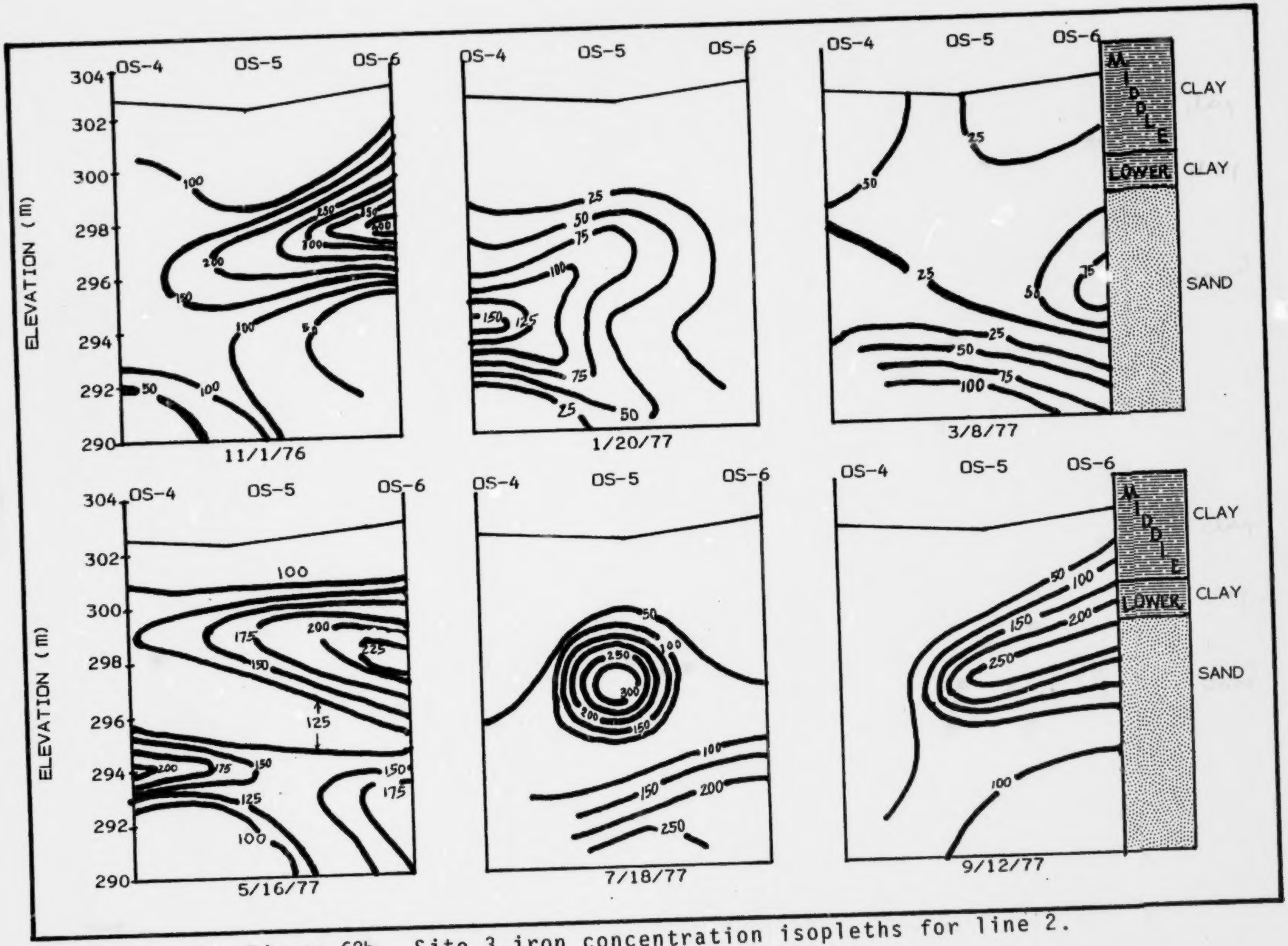

Figure 62b. Site 3 iron concentration isopleths for line 2.

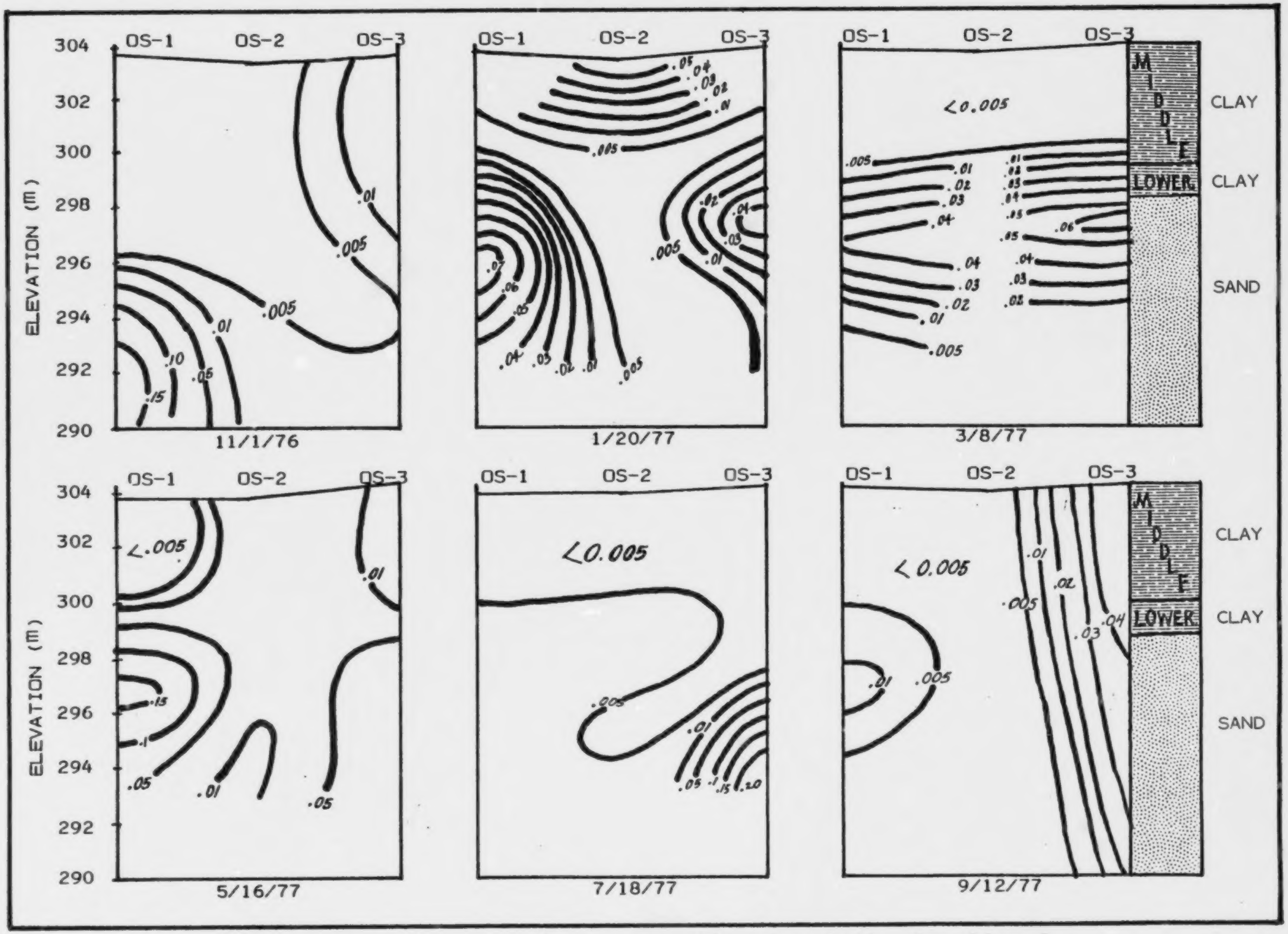

Figure 63a. Site 3 lead concentration isopleths for line 1.

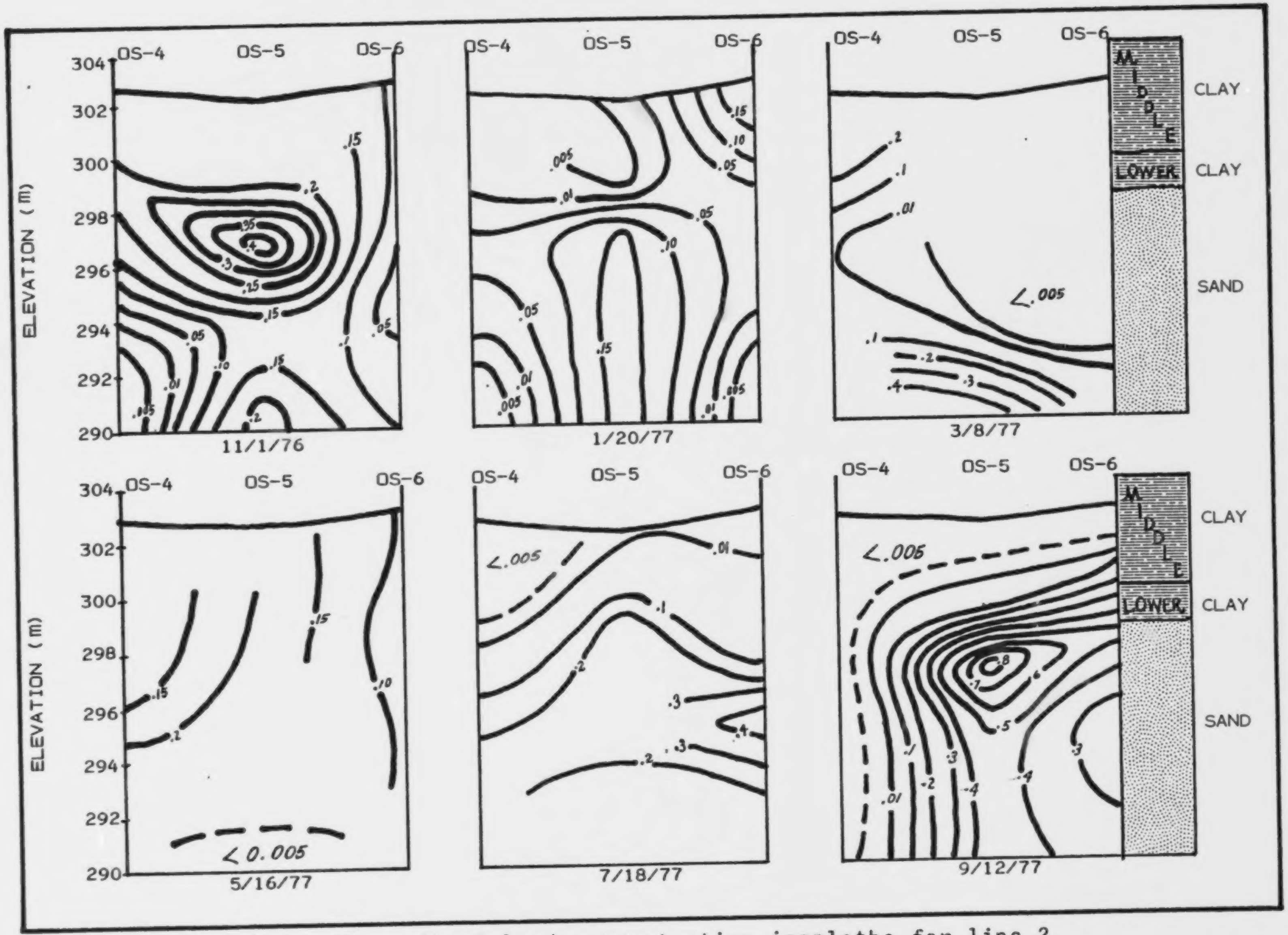

Figure 63b. Site 3 lead concentration isopleths for line 2.

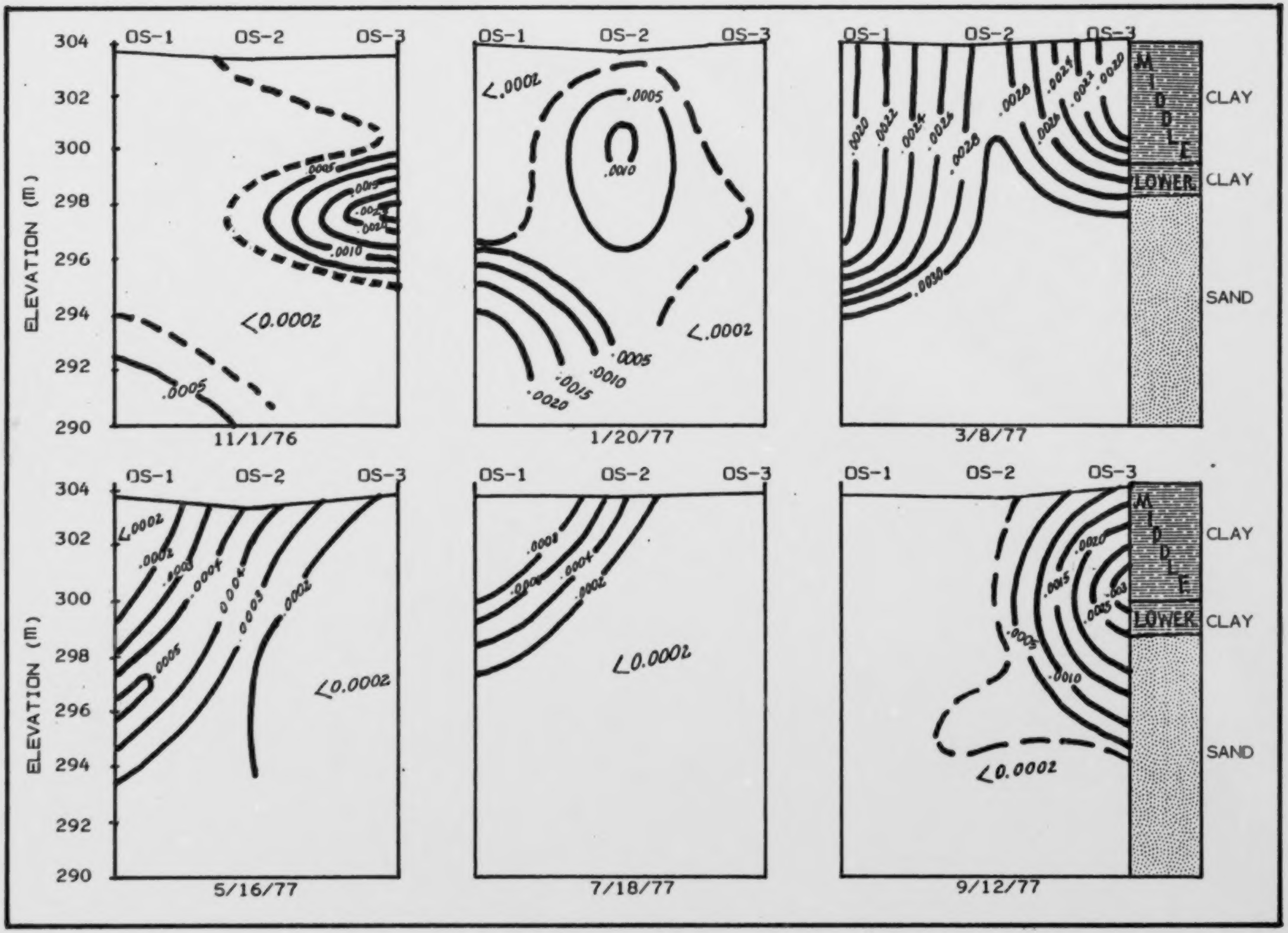

Figure 64a. Site 3 mercury concentration isopleths for line 1.

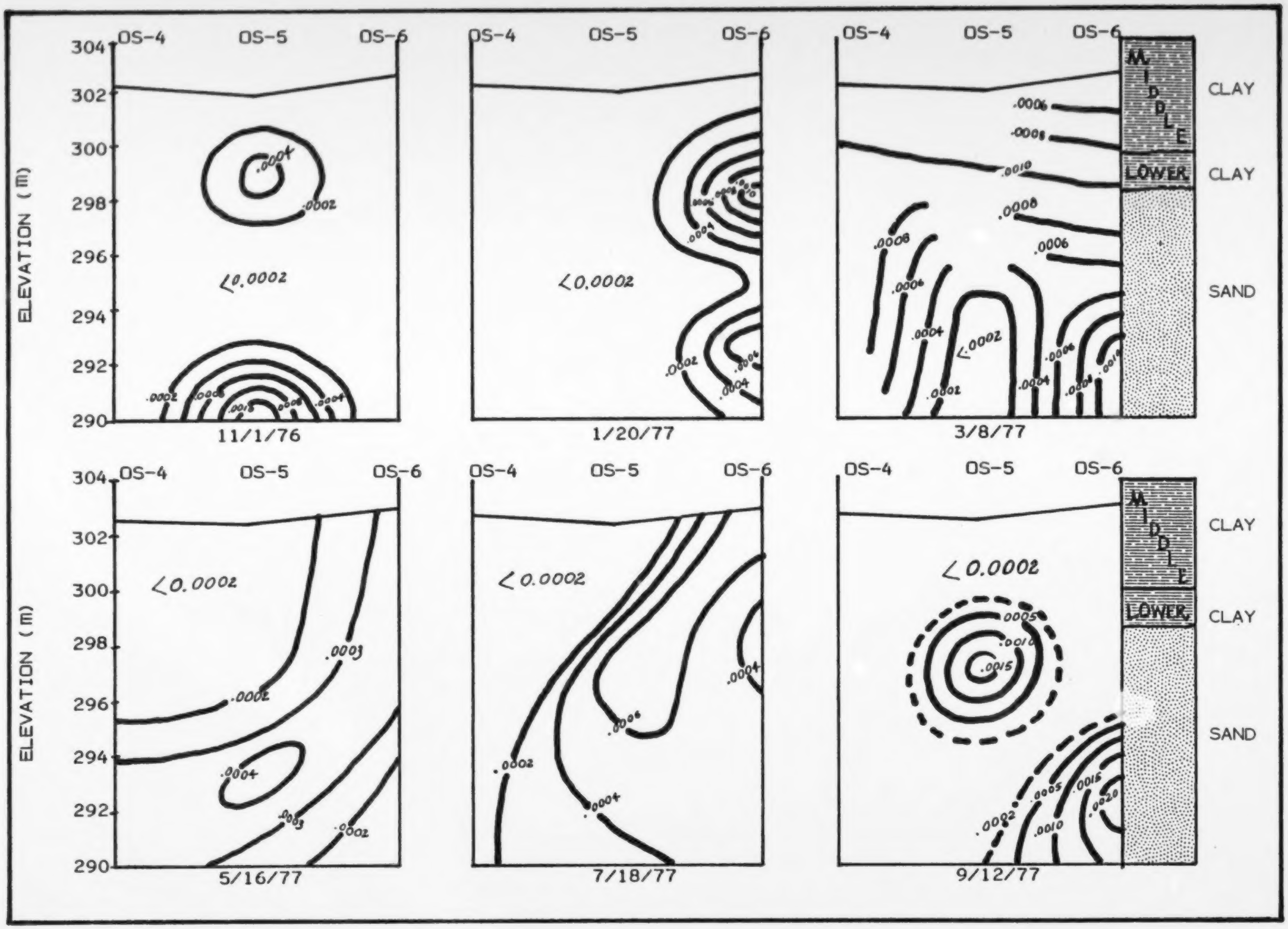

Figure 64b. Site 3 mercury concentration isopleths for line 2.

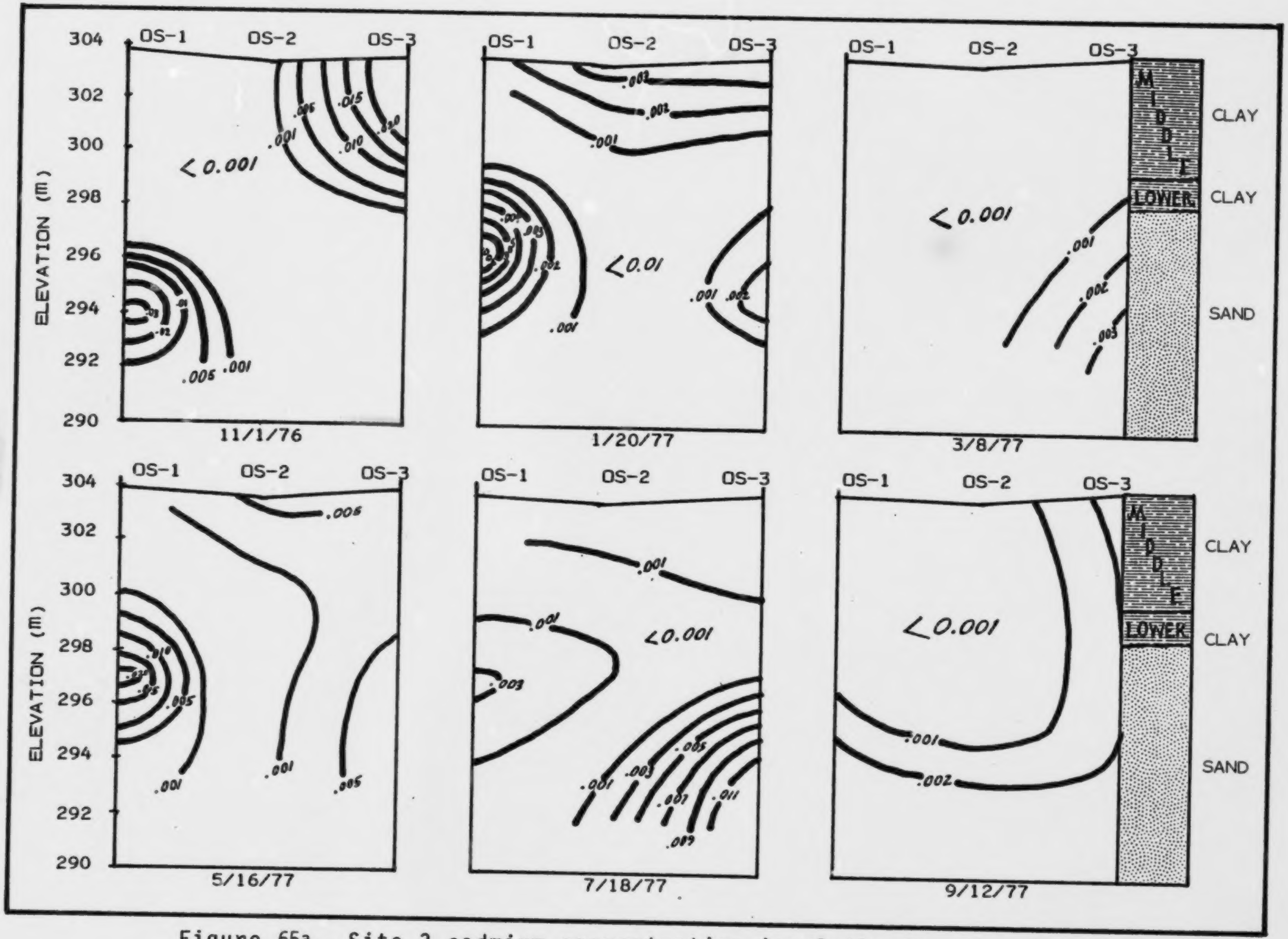

Figure 65a. Site 3 cadmium concentration isopleths for line 1.

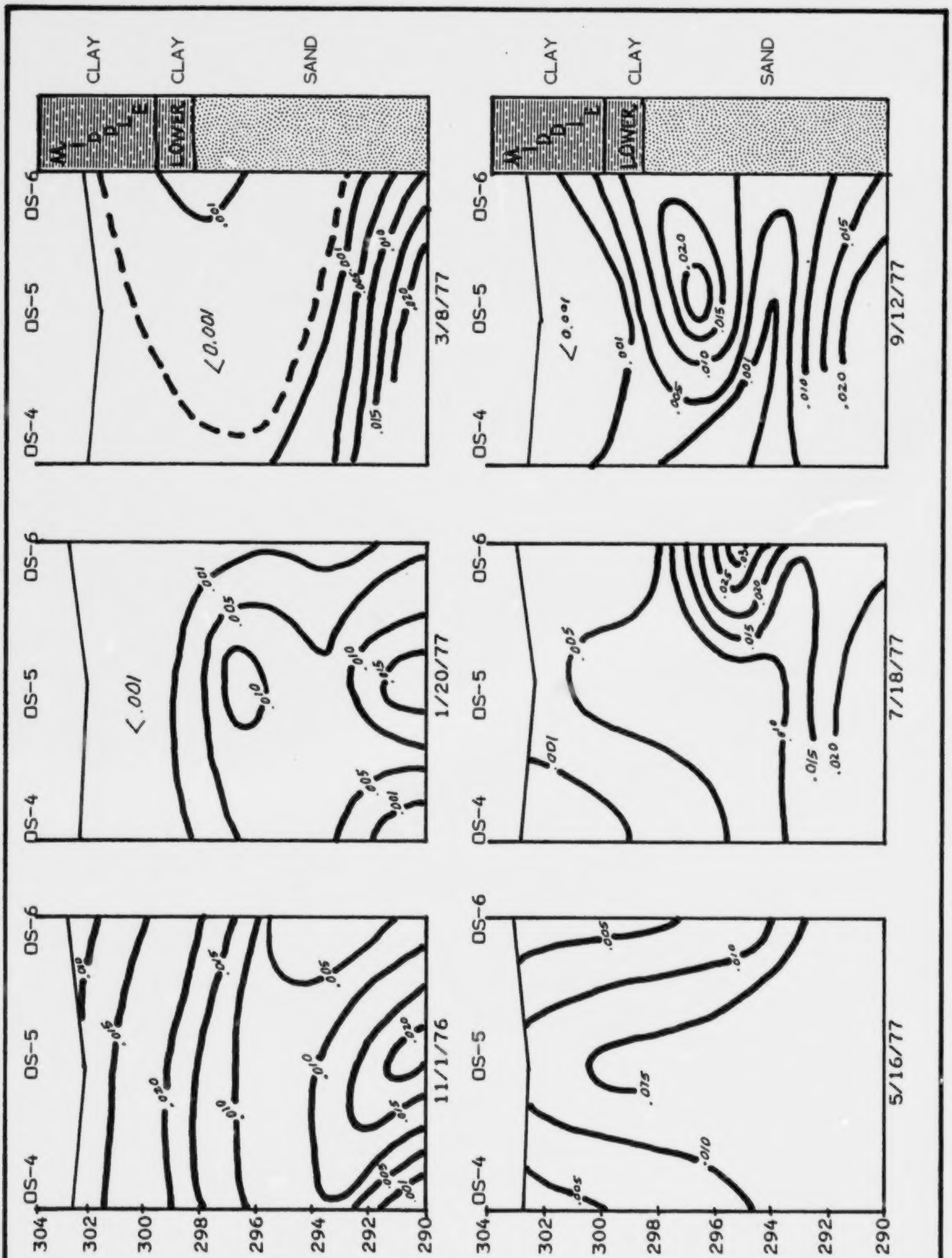

Figure 65b. Site 3 cadmium concentration isopleths for line 2.

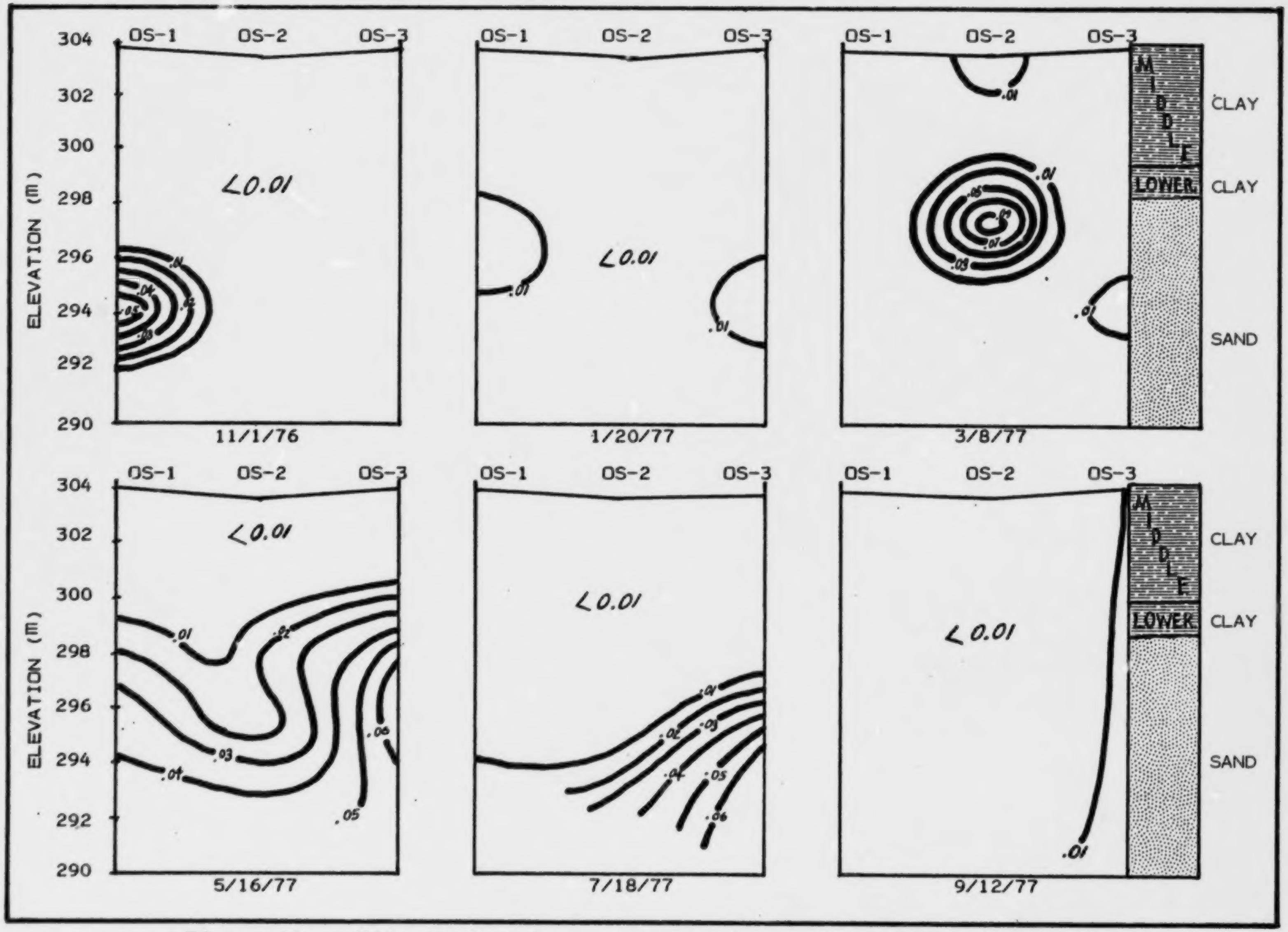

Figure 66a. Site 3 chromium concentration isopleths for line 1.

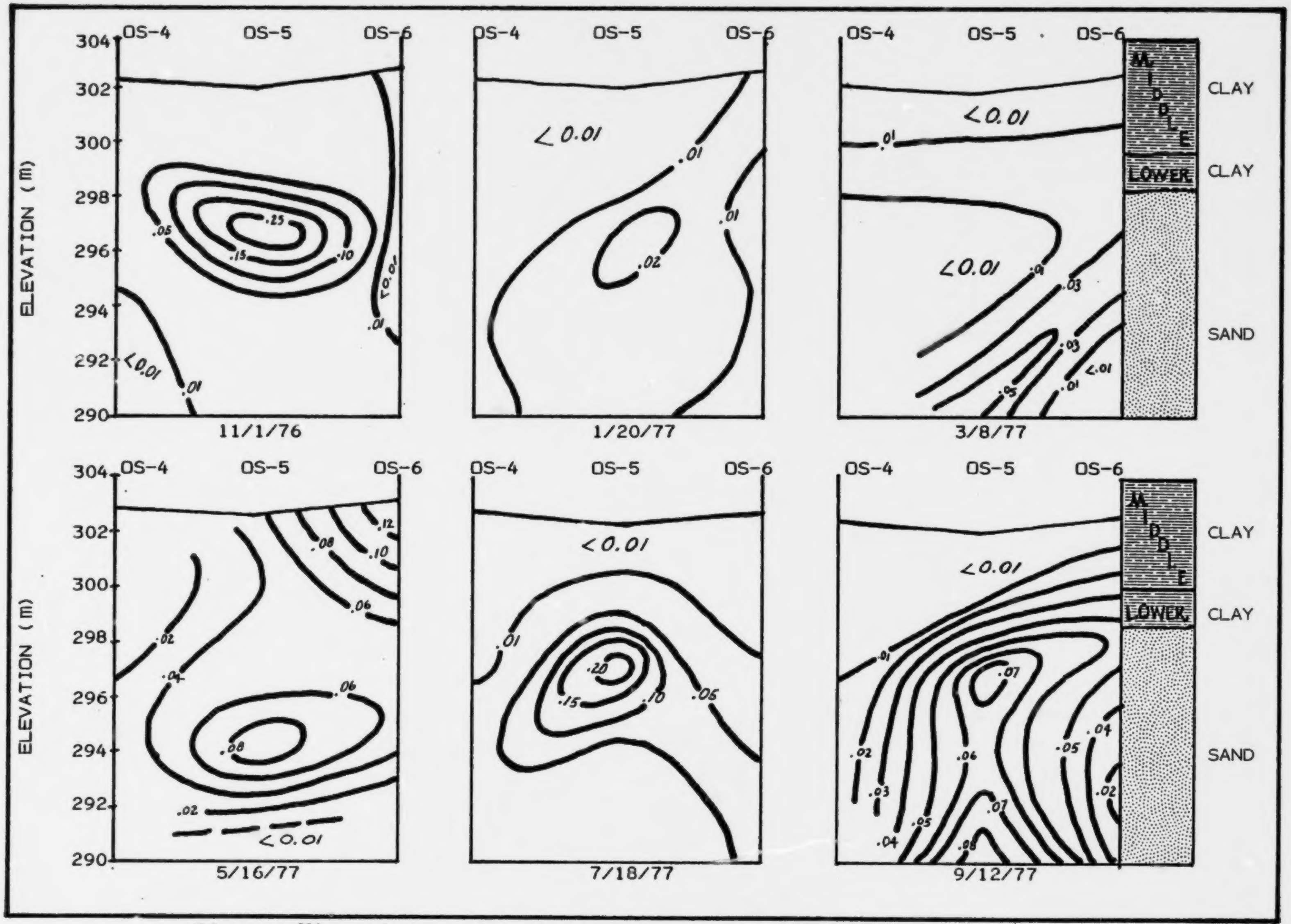

Figure 66b. Site 3 chromium concentration isopleths for line 2.

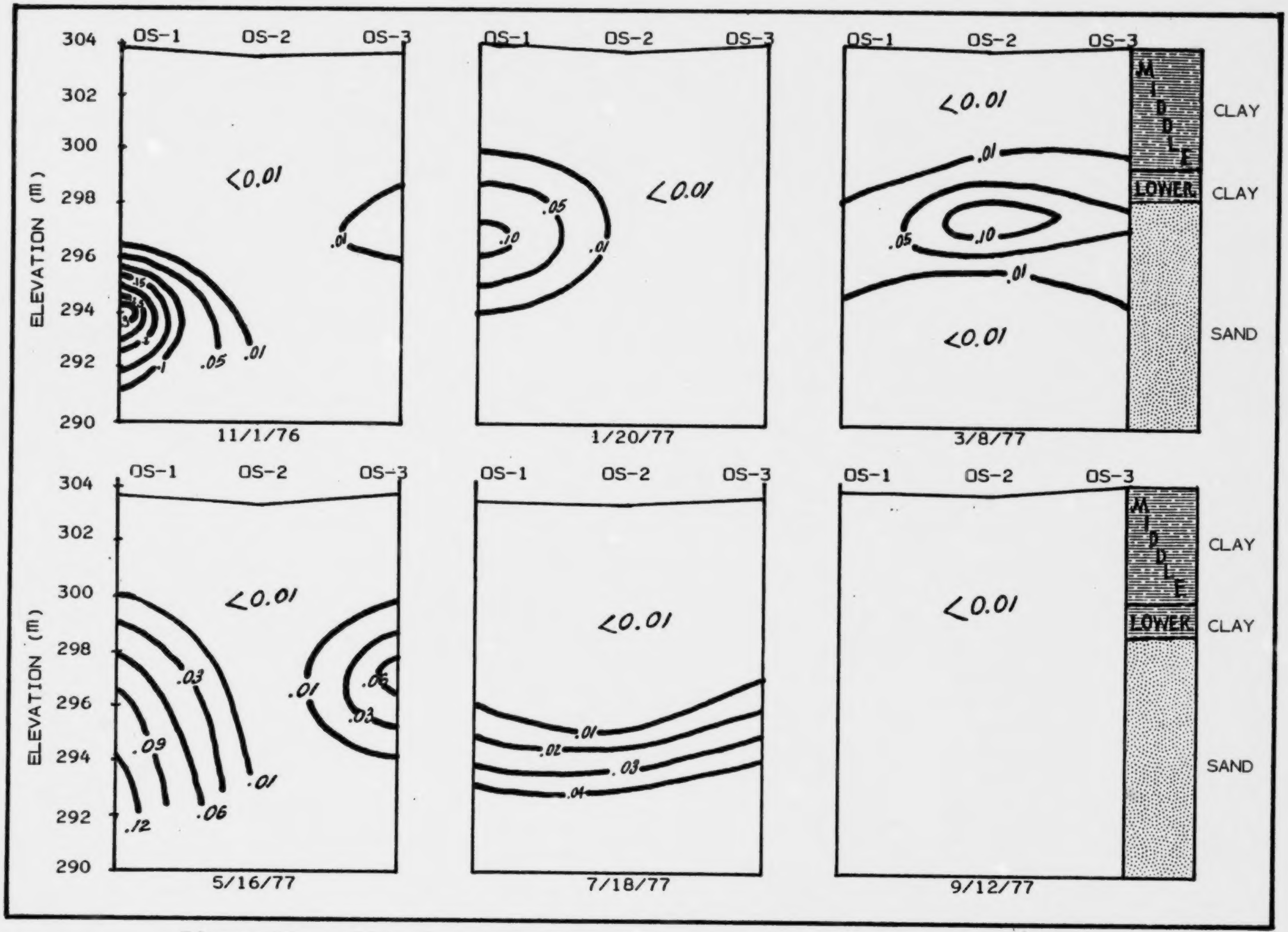

Figure 67a. Site 3 copper concentration isopleths for line 1.

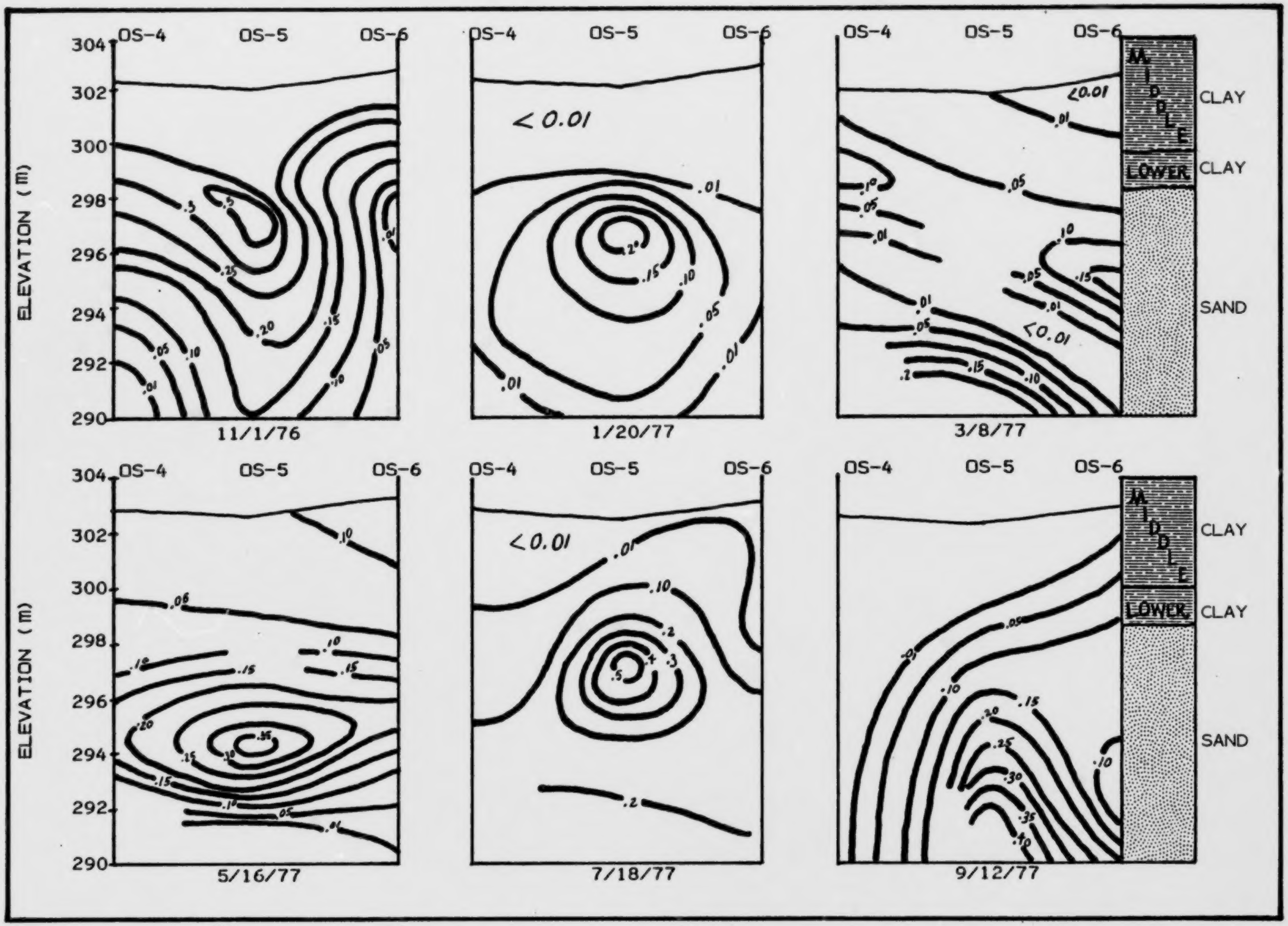

Figure 67b. Site 3 copper concentration isopleths for line 2.

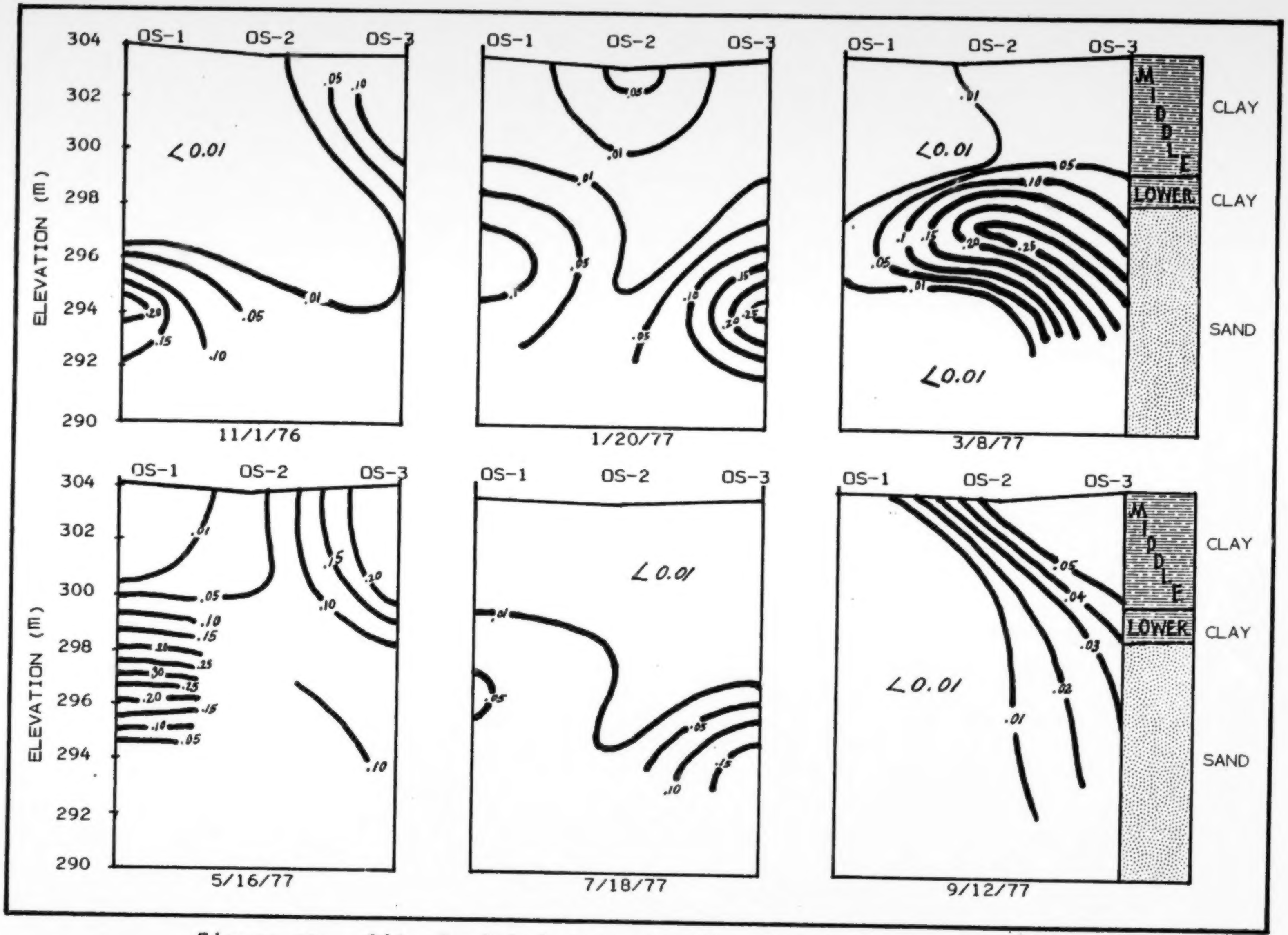

Figure 68a. Site 3 nickel concentration isopleths for line 1.

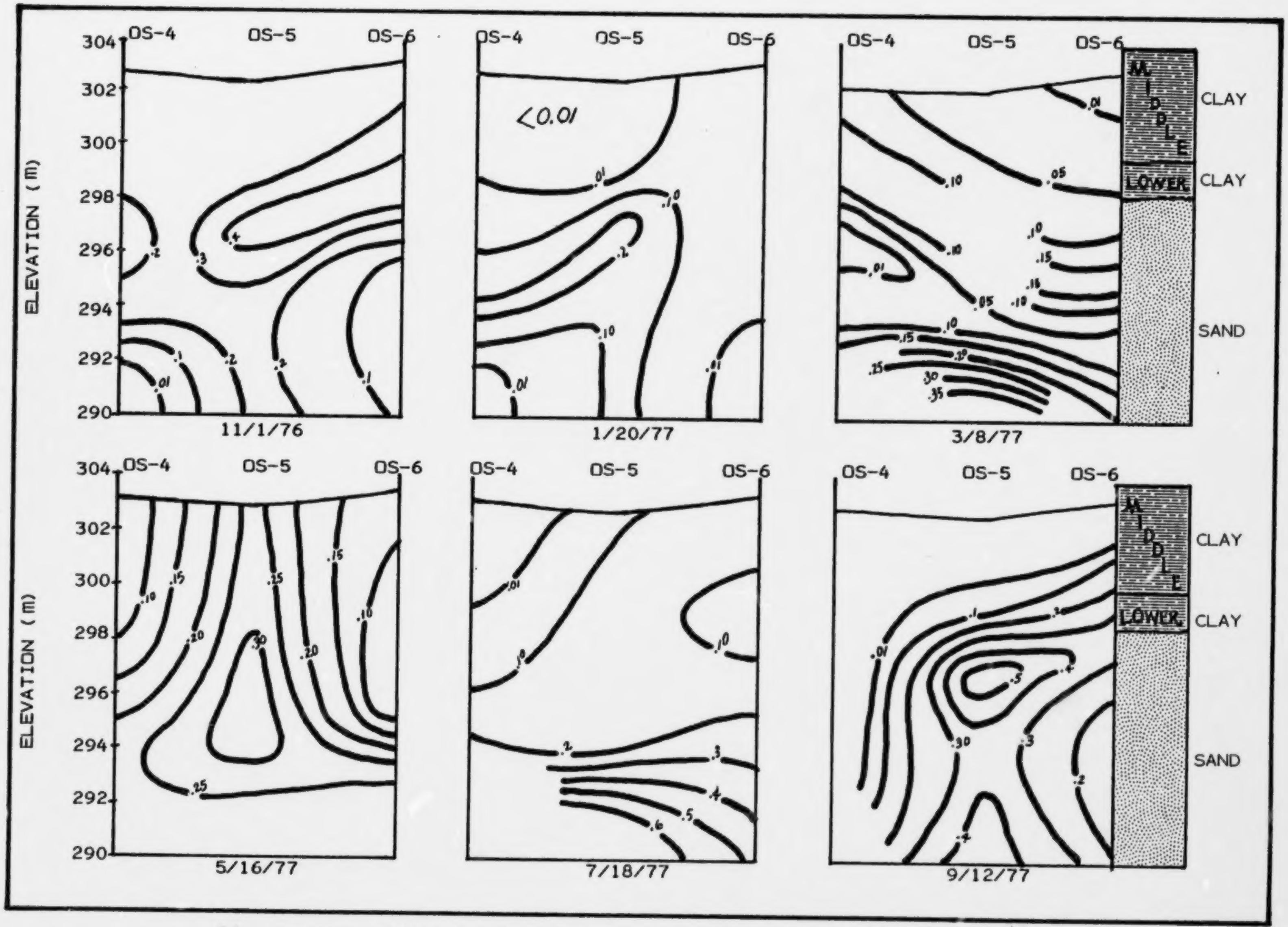

Figure 68b. Site 3 nickel concentration isopleths for line 2.

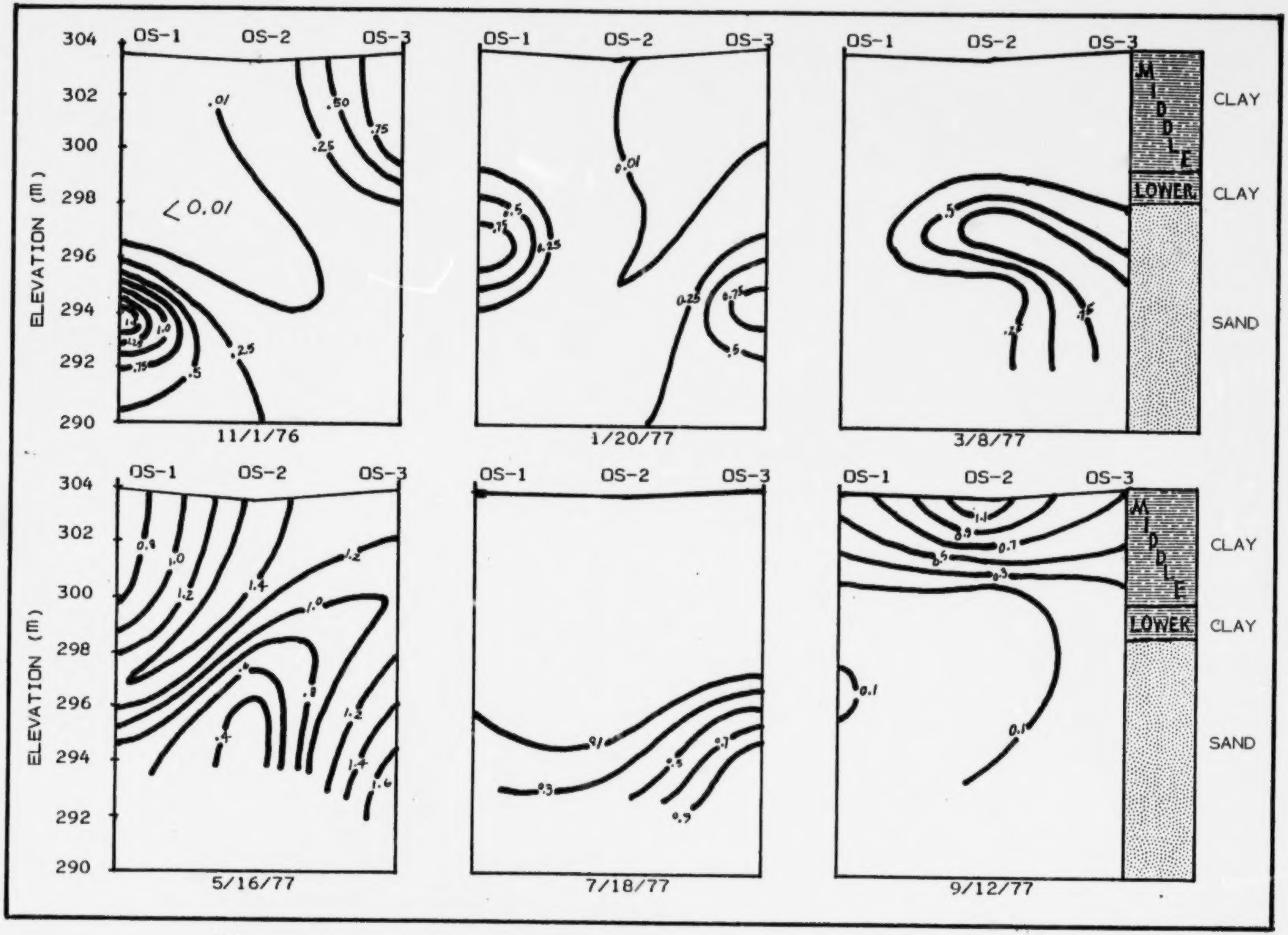

Figure 69a. Site 3 zinc concentration isopleths for line 1.

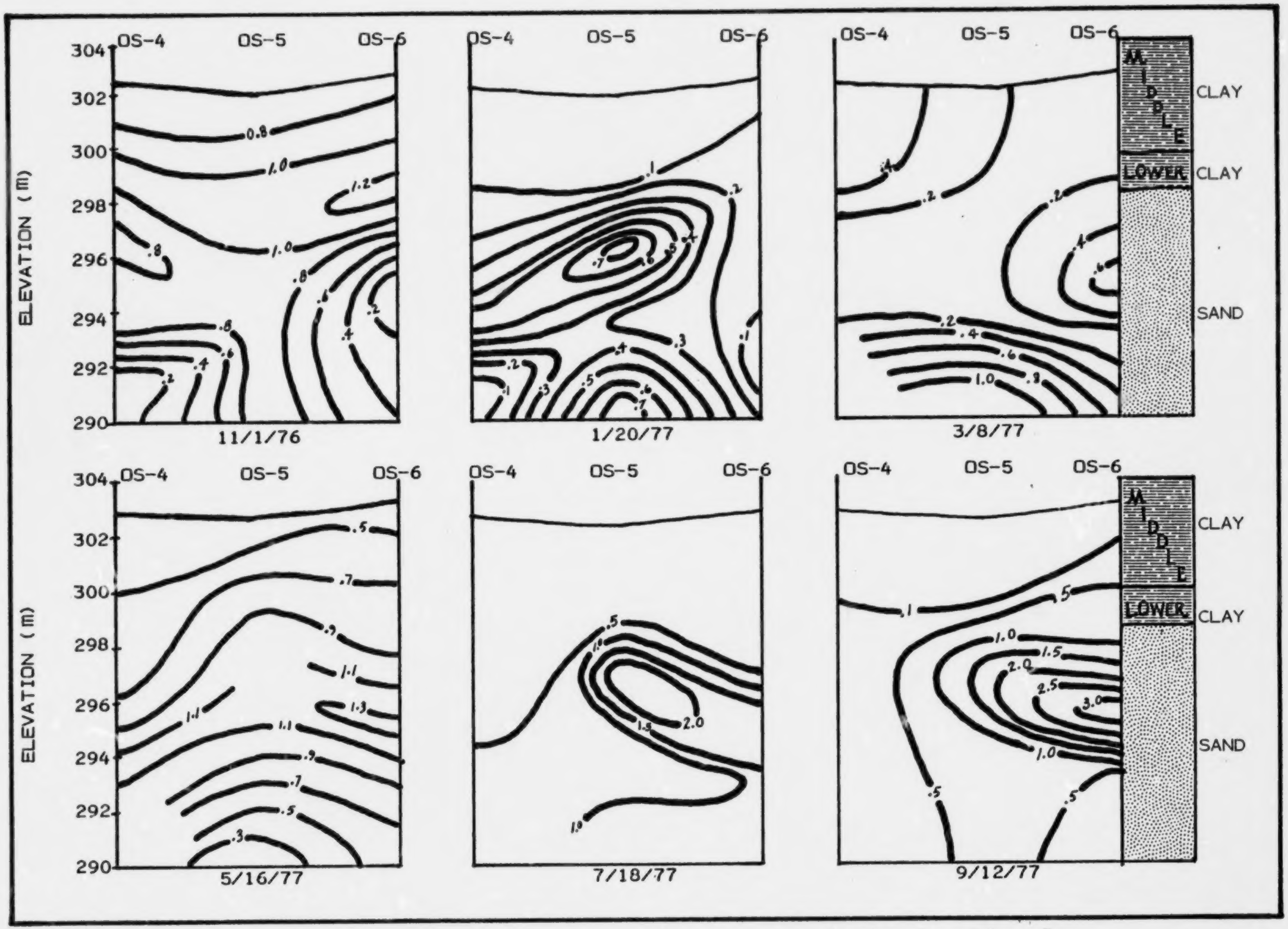

Figure 69b. Site 3 zinc concentration isopleths for line 2.

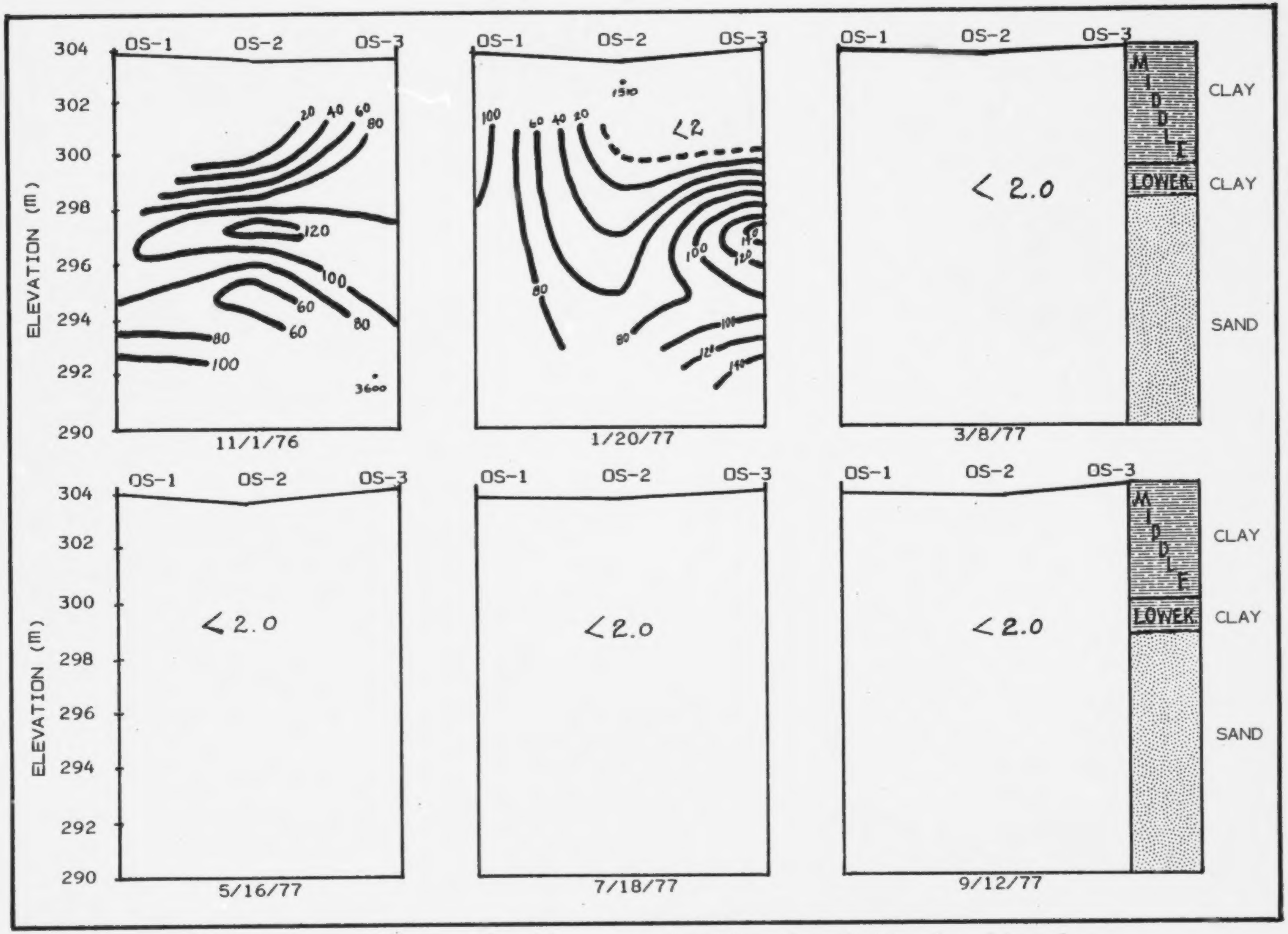

Figure 70a. Site 3 chloride concentration isopleths for line 1.

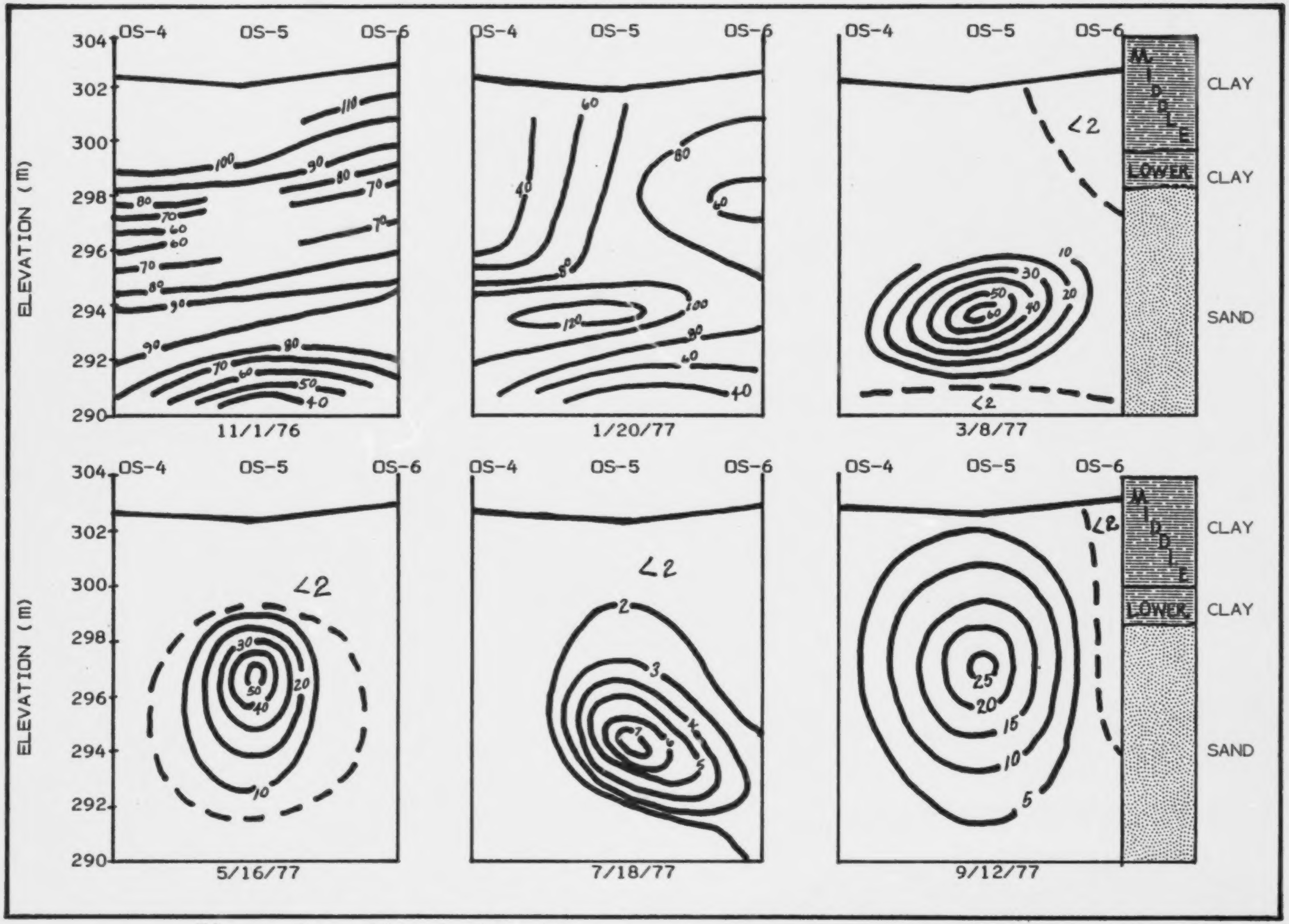

Figure 70b. Site 3 chloride concentration isopleths for line 2.

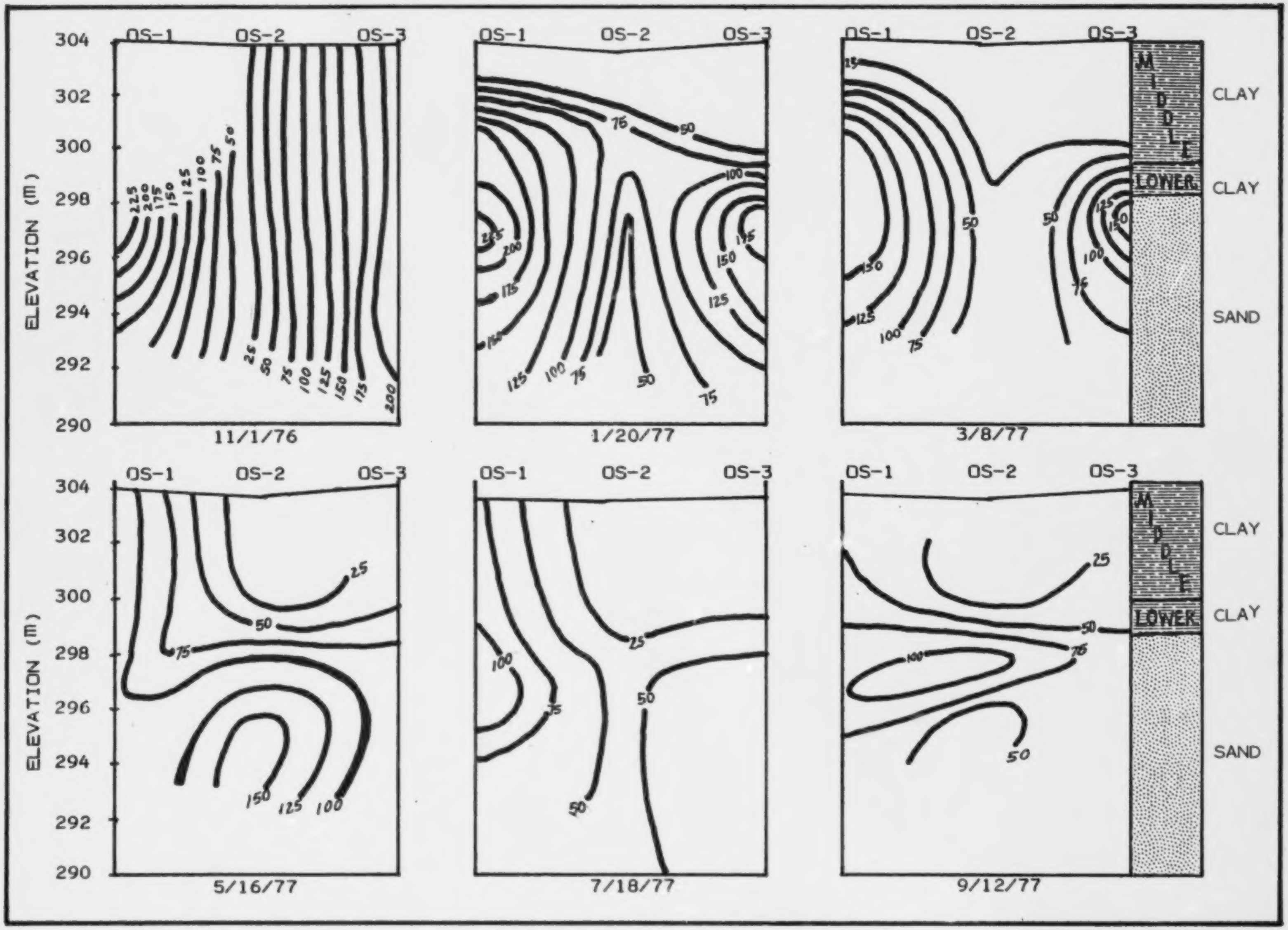

Figure 71a. Site 3 sulfate concentration isopleths for line 1.

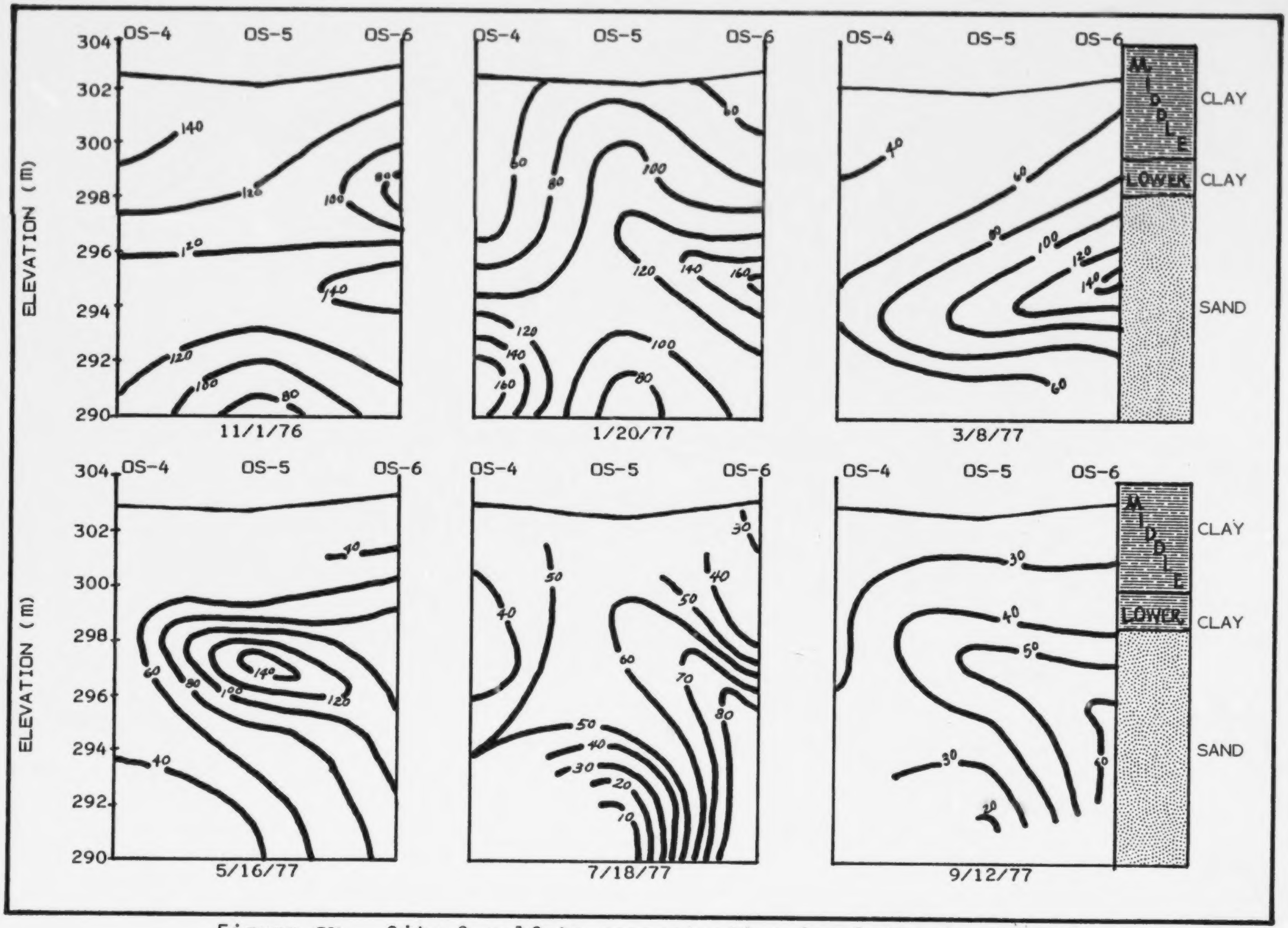

Figure 71b. Site 3 sulfate concentration isopleths for line 2.

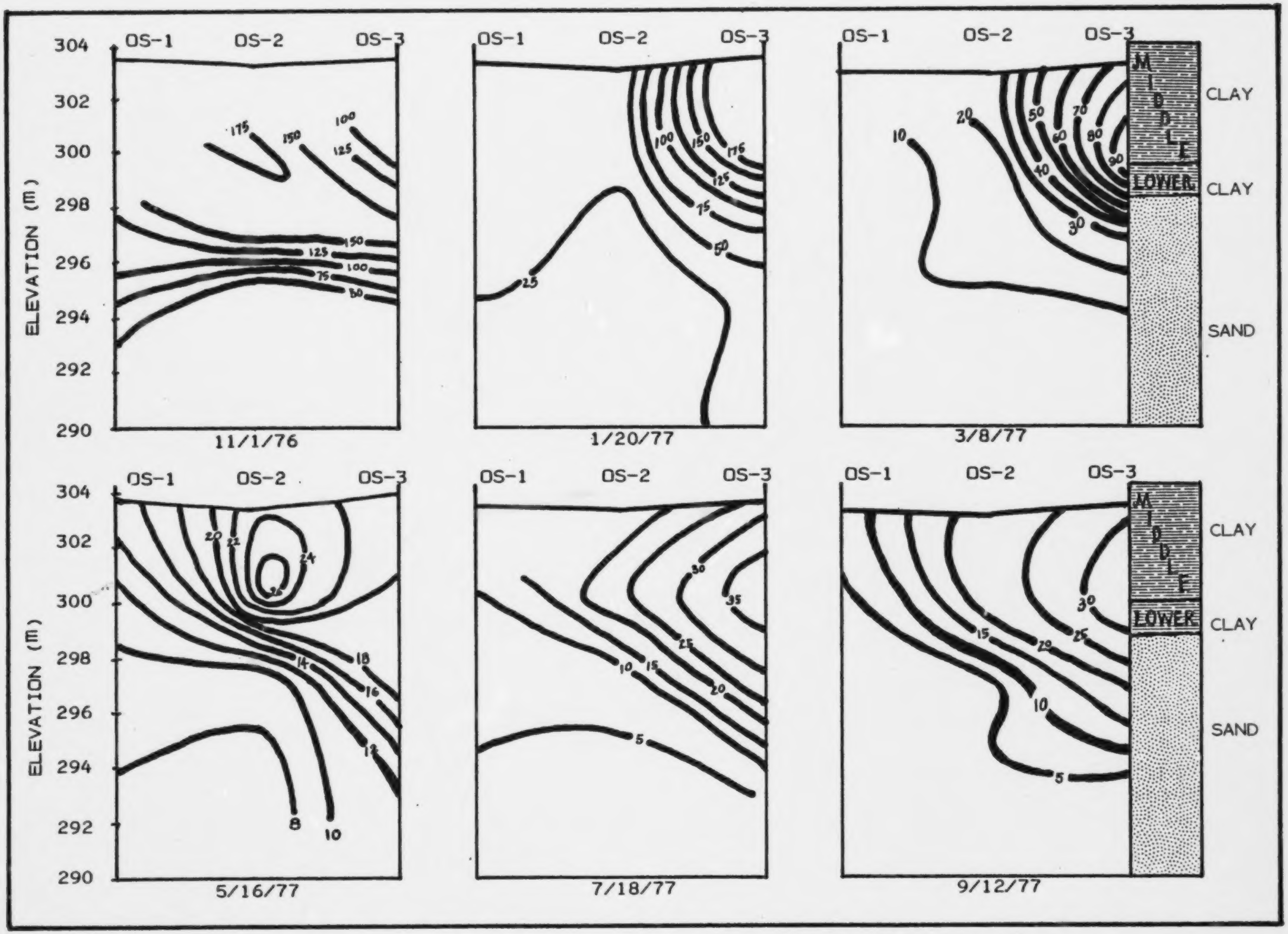

Figure 72a. Site 3 TOC concentration isopleths for line 1.

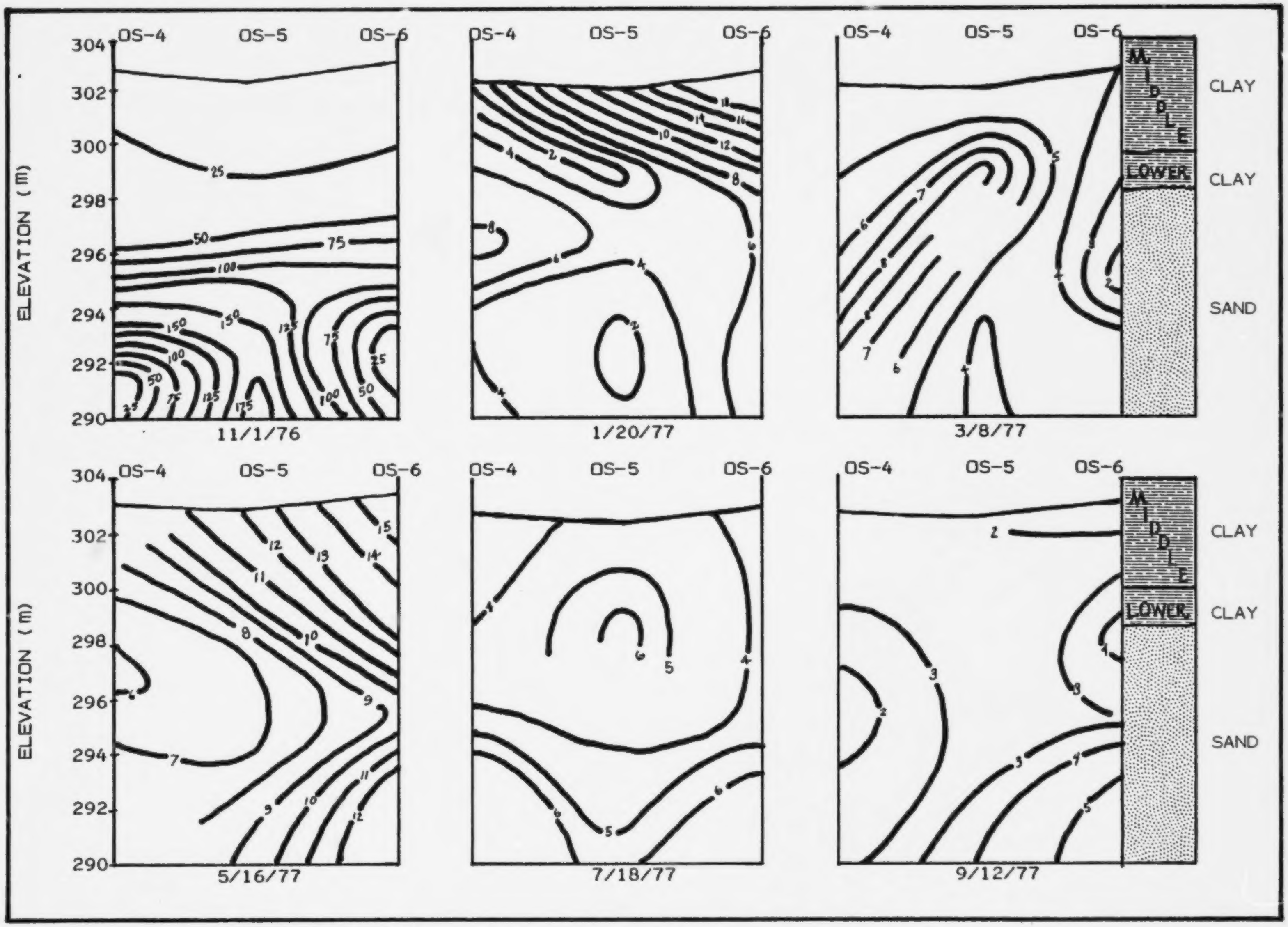

Figure 72b. Site 3 TOC concentration isopleths for line 2.

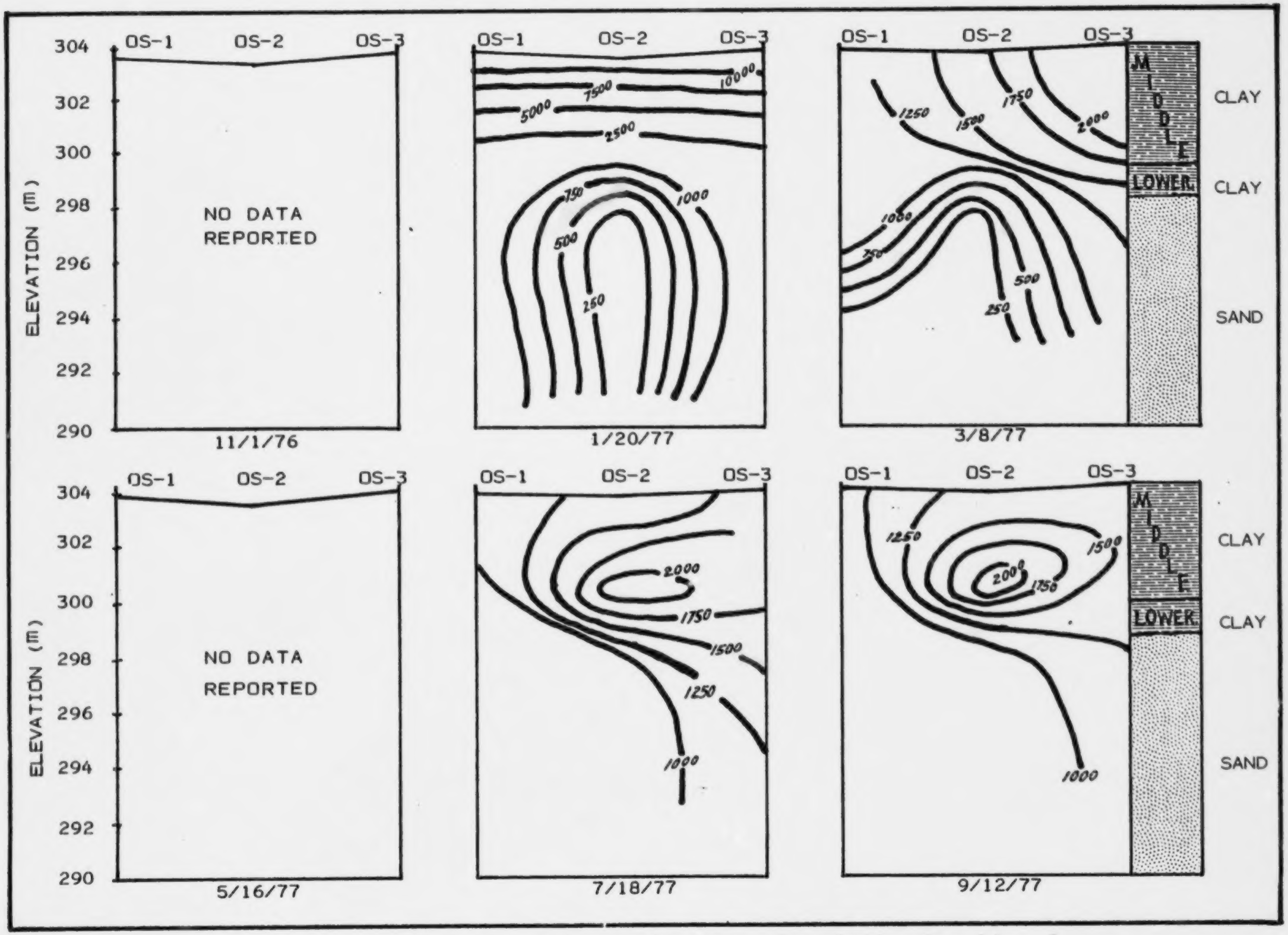

Figure 73a. Site 3 specific conductance isopleths for line 1.

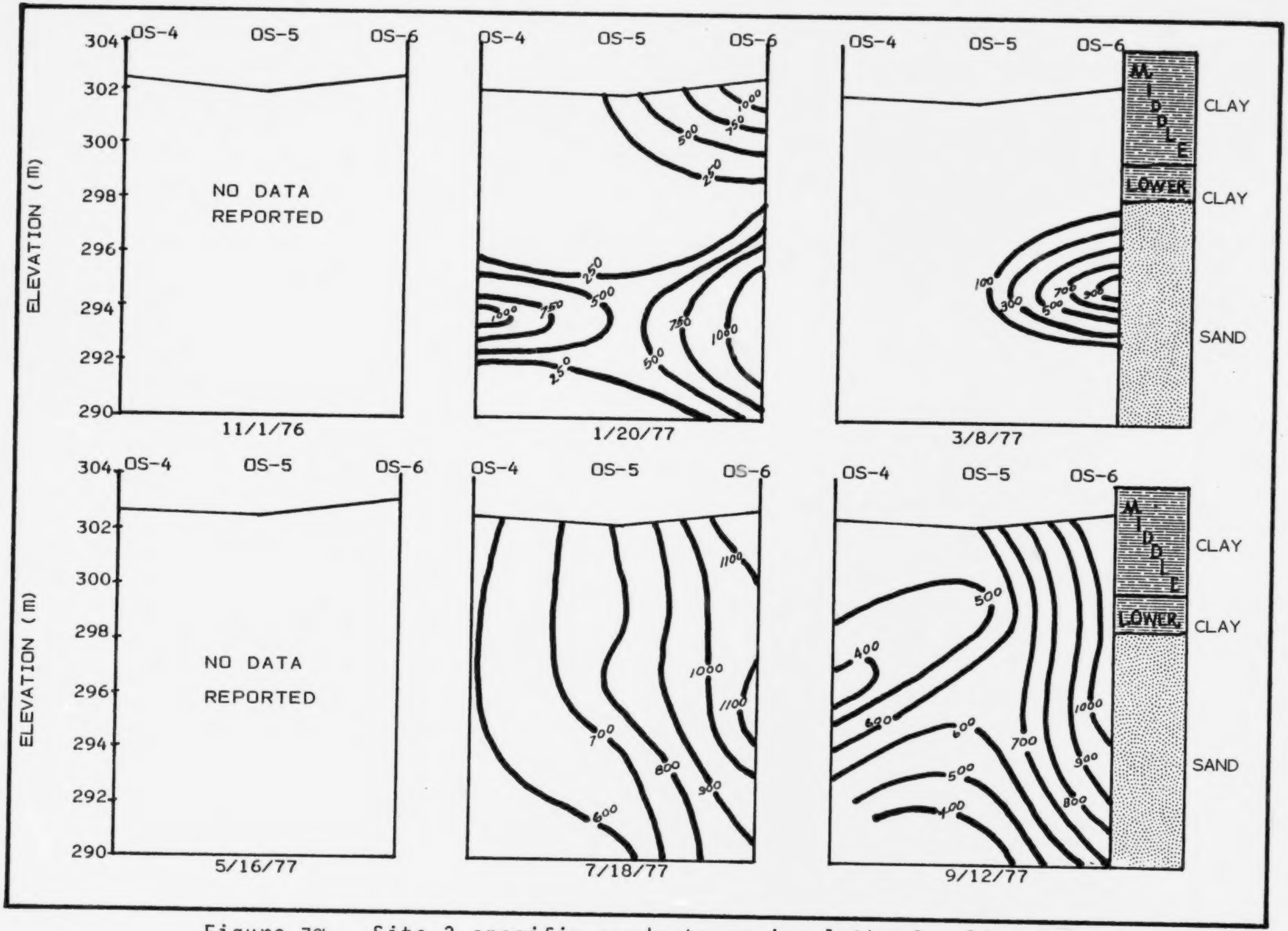

Figure 73b. Site 3 specific conductance isopleths for line 2.

absent in the next. The breakup for the specific conductance stratification, for example, suggests leachate movement through the supposedly highly impermeable middle and low clay layers at a much higher rate than was calculated. This coincides with indications by geologists of the existence of channels or cracks in the alluvial clay deposited during the geologic formation (6).

Each stratum was possibly leaching at its own controlled rate, depending on the hydraulic gradient and mounding conditions evident at the site. As a result, the leachates may have moved as highly variable and discontinuous pulses.

Predominant metal species escaping from the landfill in descending order of magnitude were iron, lead, cadmium, and mercury. Similarities existed between the concentration isopleths for iron, lead, cadmium, zinc, and nickel, with lesser similarities existing for chromium and copper (Figures 62 to 69).

For most of the contaminants, the late spring and summer months represented the periods of greatest contaminant migration. This was presumably due to the relatively high infiltration rate, allowing spring precipitation and runoff to move through the landfill. A rise in ground temperature also would increase the biological activity and chemical reaction rate, resulting in transformations and interactions in the fill and soil. These reactions and interactions, coupled with the large leachate volume generated, probably enhanced the flux of contaminants through the different soil layers and into the groundwater. As shown by the concentration isopleths for iron (Figure 62), a change in the location and orientation of the concentration gradients occurred during these periods. Instead of distinct leachate plumes separated by low ambient background quality water, the contaminants usually completely saturated the monitoring grid with relatively concentrated leachates.

The concentration isopleths for chloride indicated stratification of this contaminant during the winter months and dilution and elutriation in spring, summer, and early fall, resulting in a decrease in concentration to low levels or below detection limits (Figure 70). Similar trends were observed for sulfate, although the seasonal changes in concentration were less dramatic (Figure 71). No consistent correlations existed between specific conductance, chloride, TOC, and sulfate concentrations with those of the heavy metals monitored in the study. At times, the concentration trend of sulfate showed some correlation with the metals.

Overall, the concentration isopleths for the contaminants showed the same general pattern of two distinct major directions of heachate migration out of the landfill. These were at both ends of the monitoring grid. Careful observation of the plan

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location of the monitoring wells in relation to the landfill indicated that the major directions and points of escaping leachate were from the northern portion of the landfill where the majority of the trench operations occurred and from the southernmost portion through Wells 3 and 6. This was perhaps due to the influence of the new sludge burial operation or another component of the trench operation which was conducted farther to the east. This particular component was escaping more to the south than westward. There are indications that concentrated leachate was escaping from the middle and lower clay levels; this trend was highly dependent on the season. Various isopleths also showed that the leachate escaping from the clay strata was moving into the sand layer where it was picked up by the prevailing groundwater flow. The contaminants were not dispersed until they had traveled farther downstream. Again, the problem of proper well location and sampling depth and frequency is indicated.

Environmental Impact Assessment

This 40-yr-old disposal site, which has been used for the burial of municipal sewage sludge incinerator ash, dewatered raw municipal sewage sludge, and paunch manure, has leached considerable amounts of contaminants, particularly iron, lead, and TOC (Table 28).

Most of the leachate emanation observed during this monitoring program occurred in the lower sand stratum immediately below that of the clay containing the buried sewage sludge and incinerator ash. The upper section was composed of organic silty clay perforated with root holes in various locations, the middle of a highly plastic clay, and the lower silty clay with low to medium plasticity overlying the alluvial sand.

The quality of the three overlying clay strata (upper, middle, and lower) was a major factor in the observed concentrations and flux of leachate from the disposal area as the leachate apparently passed through the clay formation. This was evidenced by the high contaminant concentrations immediately below the clay stratum in the alluvial sand layer. It was assumed that the lower clay layer was fractured by shrinkage cracks after it was deposited and before the upper zone covered it. It is also possible that this clay is well-structured and leachate was migrating through as if it were sand. The existence and extent of cracking was unproved, but was tentatively identified through permeability testing and examination of soil boring samples taken in the field. The actual permeability of this zone could therefore be much higher than the test values indicated.

Clay is no longer recognized as a panacea for all situations. A knowledge of its mineralogical, physical, and chemical properties may explain the many different occurrences observed at this site. The soluble salts that intruded can permanently alter the

TABLE 28. NUMBER OF TIMES SAMPLED CONSTITUENT CONCENTRATIONS EXCEEDED EPA DRINKING WATER STANDARDS (SITE 3)

Constituent	Background Wells		Downstream Wells	
	Phase I	Phase II	Phase I	Phase II
Cd	0-1*	4-23	0-4	22-124
Cu	0-1	0-23	0-4	0-133
Fe	1-1	21-23	4-4	126-133
Hg	0-1	3-23	1-4	11-131
Pb	0-1	5-23	4-4	55-124
Zn	0-0	0-23	0-1	0-133
Cl	0-1	0-22	0-4	2-133
SO_4	0-1	0-23	0-4	0-132
TOC	1-1	7-22	4-4	54-131

* The first number indicates number of times standard was exceeded; the second number is sample population.

physical (e.g., swelling) and adsorptive properties of various clays. It is possible that the exchange sites were oversaturated with soluble salts, resulting in significant reduction in the adsorption for heavy metals. The data suggest that not all clay strata can be expected to provide the high degree of attenuation for contaminants under natural conditions.

Conditions for the movement of leachate were different within each stratum. High groundwater mounding apparently existed over the clay. This provided the necessary hydraulic gradient to force contaminants slowly, perhaps in a pulselike manner, laterally westward through the clay for a distance of 46 or more meters until it seeped into the adjoining creek. There was also vertical percolation through the underlying clay strata. While it may have taken 40 yr to move through the middle and lower clay strata, leachate derived from the high contaminant loading existing in this landfill has moved through these strata and is now leaching into the underlying alluvial sand stratum.

Groundwater movement in this alluvial sand stratum was determined by regional groundwater flow patterns traveling south-southwest. The flow rate in this layer is an order of magnitude greater than that in the clay, thus providing considerable dilution water for escaping leachate. However, because of the extremely high contaminant concentrations escaping from the above clay layers, high concentration leachate plumes still occurred.

A highly variable background groundwater quality also affected the results. Highly variable fluctuations were observed in background groundwater quality for iron, nickel, cadmium (primarily in the upper sampling depths), and mercury. However, significant increases over background concentration values occurred for almost all contaminants. Leachate in this alluvial sand layer could possibly intersect the adjacent creek, but the majority of it was expected to go much farther south until intersecting a major river system.

Though the landfill was located in clay, it appeared to leach a considerable amount of contaminants after a 40-yr retention period. Those contaminants originally contained in the disposal area have migrated slowly into the surrounding downstream soil strata, contaminating them as well and providing a reservoir for additional migration to subsequent downstream concentric soil zones. Had it not been for the presence of the creeks to the southwest and south of the site, this contaminant migration might have continued for many miles downstream of the disposal area.

The two adjacent creeks served as an interceptor of the leachate migrating laterally from the clay strata, effectively mixing the concentrated leachate with storm water runoff flowing through the creeks. However, it was suggested that the leachate flow through the alluvial sand layer was migrating considerable distances and contaminating a significant area downstream of the landfill. Although the exact extent of this contamination is not known, based on concentrations as well as on the leachate plume profiles observed, it was thought to be extensive. Based on the contaminant concentrations in the sludge deposited in the landfill as well as the high concentrations emanating from the site after a 40-yr existence, it was hypothesized that leaching of various contaminants from the landfill would occur for a considerable period of time into the future.

SITE 4

Soil Analyses

During the drilling of the in-refuse well, soil samples were taken from the refuse-soil interface (3.5 to 4.0 m), midway between soil and groundwater (4.6 to 4.9 m), and the soil-groundwater interface (5.8 m). These samples were sequentially extracted, first with water and then concentrated nitric acid. Results are presented in Table 29. Soils at the three depths were neutral and had similar levels of TOC, nitrate-nitrogen, chloride, and acid-extractable cadmium and mercury. Since the TOC levels were relatively low throughout (presumably background levels), and COD, TKN, and ammonium were present in largest concentrations at the refuse-soil interface, the leachate appeared to be strongly attenuated by the soil.

Large concentrations of calcium were present in water-soluble form. The element is believed to have originated from the calcareous shale and limestone deposits at lower soil depths. Very low to undetectable cadmium and mercury were found in the soil. Levels of acid-extractable copper at the refuse-soil interface and lead from the three soil depths were higher than those typically found in soils (1, 2). The lead's source cannot be determined without knowing its background level at this site. However, since the sludge did not contain a high lead content, that detected in soil was probably from the indigenous geologic materials, rather than due to the disposal of sewage sludge.

Sludge Analyses

Two grab sludge samples taken one year apart from the sewage treatment plant were sequentially extracted, first with water and then with concentrated nitric acid. Results show significantly higher concentrations of TOC, chloride, and sulfate in the 1976 sample than those from 1975 (Table 29). None of the heavy metals, including lead and copper, was present at elevated concentrations when compared to published data (9). These metals were principally in the acid-extractable form. The 1976 sample contained higher levels of cadmium, chromium, and copper, and lower levels of lead, mercury, and iron when compared to the heavy metal contents in the 1975 sample. Since the sludge was strongly alkaline (pH 12.3), a low solubility of these sludge-borne heavy metals in water was expected, resulting in their limited movement away from the landfill.

Leachate Analyses

Leachates collected from the in-refuse well during Phases I and II were analyzed for selected constituents (Table 30). Concentrations of the various constituents were generally greater

TABLE 29. ANALYTICAL RESULTS FOR SITE 4, PHASE I*

	Soil Samples Taken Below Landfill During Drilling of In-Refuse Well					
	Refuse-Soil Interface (3.7 to 4.0 m)		Midway Between Soil & Groundwater (4.6 to 4.9 m)		Soil-Groundwater Interface (5.8 m)	
Constituent†	Water	Acid	Water	Acid	Water	Acid
	6/26/75		6/16/75		6/16/75	
pH	7.1		7.0		7.2	
TOC	960		800		1020	
COD	1610		920		1035	
TKN	227		17		42	
NH_4-N	193		<1		6	
NO_3-N	10		9		14	
Cl	132		110		105	
SO_4	<40		187		50	
Ca	118	90	98	136	178	96
Cd	<0.01	0.68	0.01	0.68	<0.01	0.56
Cr	0.30	62.30	<0.30	39	<0.30	31.50
Cu	1.4	44	<0.1	13	1.2	11
Fe	12.6	26458	1.5	18416	4.0	17437
Hg	0.008	0.009	0.009	<0.006	<0.001	<0.010
Pb	0.5	22	0.5	32	0.9	18
Moisture, %	24.1		27.3		27.4	

TABLE 29. (continued)

Constituent†	Sludge#				Background Groundwater	
	6/17/75		6/5/76			
	Water	Acid	Water	Acid	10/10/75	6/5/76
pH	12.3				7.6	
Tot. Solids					201	
TOC	3600		30465		39	13
COD	4412				41	
MBAS			<0.1			<0.01
TKN	534				0.7	
NH_4-N	137				<0.1	
NO_3-N	0.7				0.36	
Cl	1187		3250		2	13
SO_4	230		625		11	870
Ca	5889	14000			12	
Cd	0.03	1.5		2.8	0.002	0.002
Cr	0.30	13.17		34	0.01	0.01
Cu	8.8	85		108	0.007	<0.01
Fe	3.3	5960		3750	1.32	1.4
Hg	<0.001	0.010		<0.003	0.001	<0.0002
Ni				8.6		0.02
Pb	1.2	28		16	0.010	0.04
Zn				88		0.02
Moisture, %	82.9		85			

TABLE 29. (continued)

Constituent†	Offsite Well (Shallow)			
	7/8/75	10/8/75	11/3/75	6/5/76
pH	7.2	7.9	7.6	
Tot. Solids	2087	1941	2066	
TOC	8	28	15	1.5
COD	19	30	20	
MBAS				<0.01
TKN	2.1	1.3	0.7	
NH_4-N	0.4	0.3	<0.1	
NO_3-N	0.10	0.45	0.85	
Cl	50	65	87	81
SO_4	900	912	825	1050
Ca	350	160	275	
Cd	0.006	0.004	0.004	0.003
Cr	0.05	0.01	0.02	<0.01
Cu	0.074	0.015	<0.006	<0.01
Fe	0.13	0.20	0.17	0.18
Hg	0.005	0.0002	<0.0002	<0.0002
Ni				0.02
Pb	0.120	0.062	0.070	0.02
Zn				0.02

* Soil and sludge were extracted with water and conc. nitric acid. Sampling dates are also indicated.

† Concentrations are expressed as mg/kg of dry soil, mg/kg of wet sludge, mg/l of groundwater or leachate.

# Moisture contents were 82.9 and 85% for the 6/17/75 and 6/5/76 samples, respectively.

TABLE 30. CHEMICAL ANALYSIS OF LEACHATES FROM IN-REFUSE WELL (SITE 4)

Constituent*	Phase I			
	7/8/75	10/10/75	11/13/75	6/5/76
pH	7.1	7.4	8.3	
Tot. Solids	5411	6948	23760	
TOC	4960	4320	4160	227
COD	8570	5443	10998	
MBAS				0.51
TKN	1459	1082	1058	
NH_4-N	1432	986		
NO_3-N	<0.02	<0.02		
Cl	508	624	596	680
SO_4	60	1		16
Ca	317		2248	
Cd	0.060	0.025	0.216	0.003
Cr	9.50	3.30	51.64	0.08
Cu	4.70	2.12	36.34	<0.01
Fe	124	42	350	12
Hg	0.005	0.0005	0.003	<0.0002
Ni				0.08
Pb	0.760	0.345	3.530	0.02
Zn				0.01

TABLE 30. (Continued)

Constituent[*]	Phase II					
	11/23/76	1/19/77	3/7/77	5/21/77	7/21/77	9/16/77
Cd	0.010	<0.005	0.005	0.005	<0.005	<0.005
Cr	0.06	0.85	0.11	0.14	0.14	0.11
Cu	0.07	0.08	0.05	0.05	0.08	0.03
Fe	13.00	1.50	0.80	0.21	20.00	13.00
Hg	<0.0002	0.0005	0.0002	<0.0002	0.0002	<0.0002
Ni	0.12	0.09	0.09	0.18	0.12	0.07
Pb	0.200	0.090	0.470	0.080	0.095	0.150
Zn	0.13	0.23	0.29	0.12	0.04	0.08
Cl	4	4	5	2	4	2
SO_4	1	5	10	1	<1	<1
TOC	146	485	128	105	97	93
Sp. Cond.	--[†]	2650	520	--	6900	6025

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[*] Specific conductance in µmhos/cm, all other constituents concentrations in ppm.

[†] Insufficient sample.

in 1975 than they were in 1976, or in Phase II. Variations in constituent concentrations were noted with sampling dates.

Nitrogen existed primarily in the ammonium form. Levels of total solids, TOC, COD, chloride, chromium, copper, iron, and lead in the 1975 samples were relatively high. Chromium and lead levels in the November 1975 sample increased to 51.6 and 3.5 ppm, respectively. This is somewhat surprising since the strong alkalinity (pH 8.3) of the leachate would have precipitated these metals out of the solution phase. The dramatic decreases in concentration of the constituents measured in the leachates during Phase II were probably due, in part, to dispersion and dilution resulting from large quantities of leachate generated following rainfall.

Groundwater Analyses

Chemical analyses of groundwater are presented in Table 29 and in Table 4 of Appendix E for Phases I and II, respectively.

Background Groundwater--

The background groundwater from a private well in Phase I monitoring showed similar concentrations of heavy metals between the two sampling dates (Table 29). While the TOC concentration decreased, concentrations of chloride, and particularly sulfate, increased in the 1976 sample. In Phase II, a new background well was installed in an upstream location south of the landfill. Concentrations of various contaminants detected in the groundwater from this well were in the same order of magnitude as concentrations in the background groundwater in Phase I. Cadmium, chromium, copper, mercury, and nickel levels were generally near or below detection levels in the background groundwater of Phase II. The September 1977 sample, however, showed slightly elevated concentrations of mercury, nickel, lead, zinc, and chloride, as well as specific conductance. The changes in contaminant concentrations with time illustrate the dynamic environment of groundwater and the significance of sampling frequency in providing a true picture of groundwater quality.

Overall, the levels of TOC, iron, and chloride in the background well were generally close to those in the downstream well, (Figures 74 and 75). Other background contaminant levels were lower than the corresponding levels found in the downstream well.

Groundwater from Off-site Well--

Only one shallow off-site well was installed (at 4.9 m) at this site due to the presence of limestone bedrock that prevented deeper drilling. It was intended only to intercept any surface or near subsurface water than might tend to migrate along the soil/bedrock plane.

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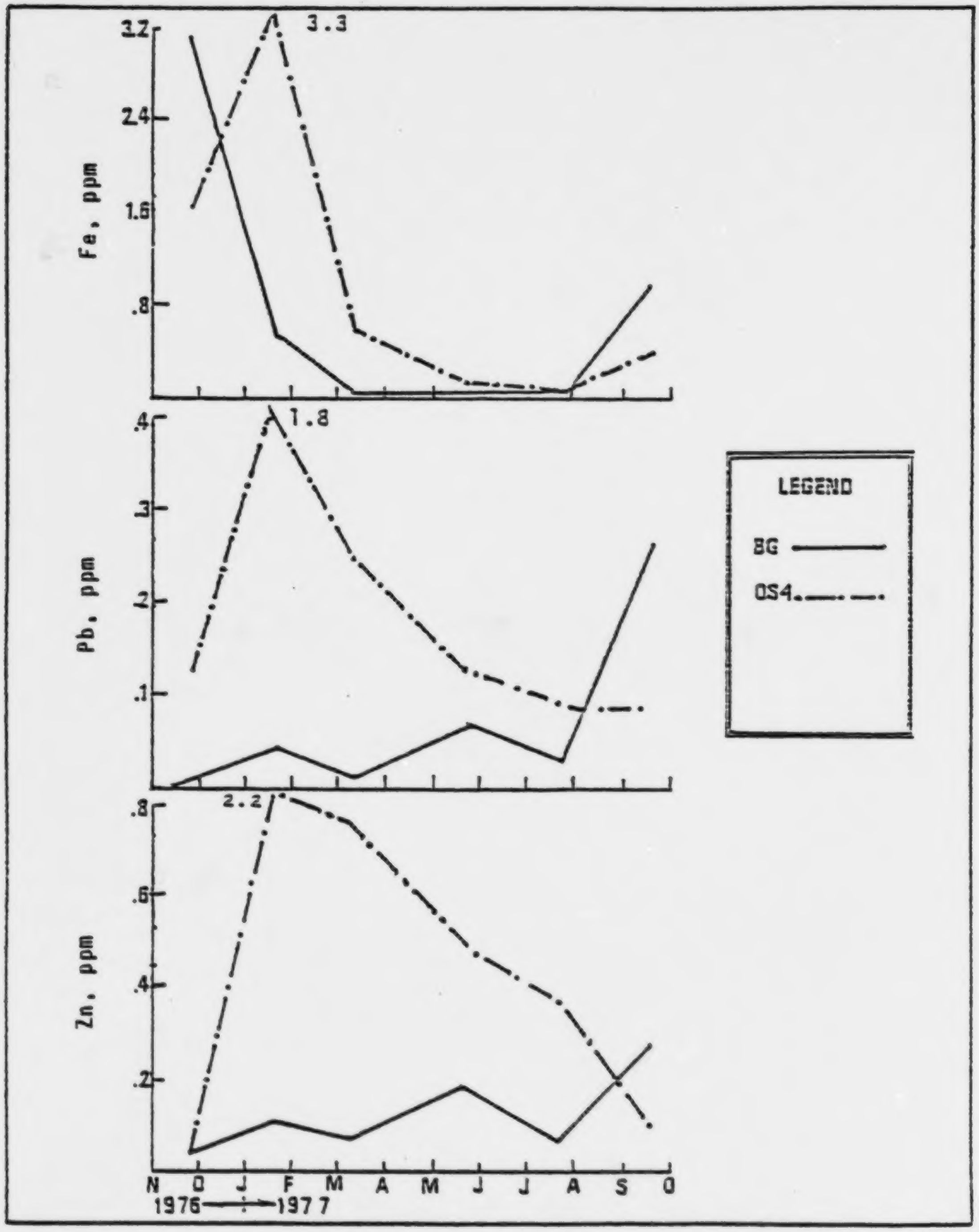

Figure 74. Fe, Pb, and Zn levels in groundwater. (Site 4)

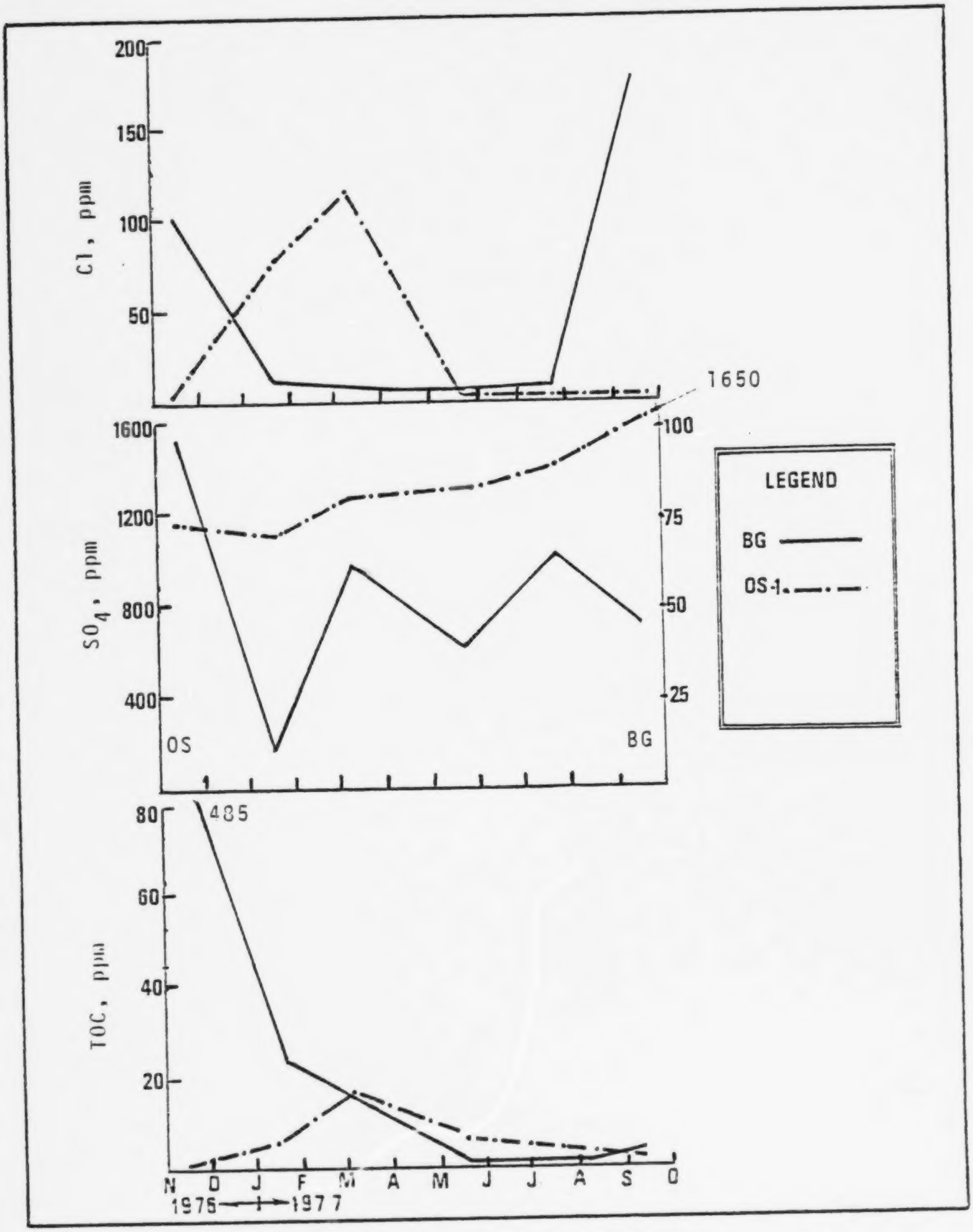

Figure 75. Cl, SO_4, and TOC levels in groundwater. (Site 4)

Groundwater from the off-site well was characterized by exceedingly high levels of total solids (2,031 ppm), calcium (262 ppm), and sulfate (922 and 1,312 ppm). There were indications that these high contaminant levels were due to existing geologic materials (e.g., limestone and black shale layers), and intrusion of the river water.

Except for lead, the heavy metals were detected at very low levels, particularly during Phase II monitoring. The increase in lead concentration in downstream groundwater was related to its relatively high content in the soil. As indicated earlier, its source might be indigenous rather than sludge-borne. However, it was necessary to determine the lead content in soil taken at the same depth outside the zone of landfill influence to establish its source in the disposal area.

Iron concentrations in the downstream groundwater were generally lower than the concentrations found in other case study sites. These were at background groundwater levels showing the profound effect of soil attenuation (by limestone, sulfide, and clay), since the soil and the sludge buried at this site had relatively large quantities of total iron.

Environmental Impact Assessment

Since this landfill receives only sewage sludge, there has been concern about the possible contamination of ground and surface waters by chemical constituents and bacterial pathogens resulting from the disposal operation. To determine groundwater quality, concentrations of various contaminants in the groundwater were compared with EPA drinking water standards (Table 31). In addition, bacteriologic examination of one off-site groundwater sample was also included in the evaluation.

Background Groundwater--

The parameters in the background groundwater that exceeded drinking water standards were iron, mercury, lead, sulfate, and TOC.

Iron levels in the background groundwater were not exceedingly high, although the standard was exceeded on four of eight occasions. In Phase II monitoring, except for the first sampling round, iron concentrations in groundwater at the background well were relatively low when compared to the data obtained for other case study sites. Nevertheless, the data indicated an elevated level of iron in the background groundwater.

The level of mercury exceeded the standard twice in the background groundwater of Phase II. This finding was not substantiated by the downstream groundwater, soil, sludge, and leachate data since mercury concentrations in these sources varied from low to nondetectable. Lead also exceeded the standard

TABLE 31. NUMBER OF TIMES SAMPLED CONSTITUENT CONCENTRATIONS EXCEEDED EPA DRINKING WATER STANDARDS (SITE 4)

Constituent	Background Wells		Downstream Wells	
	Phase I	Phase II	Phase I	Phase II
Cd	0-2*	0-6	0-4	0-6
Cu	0-2	0-6	0-4	0-6
Fe	2-2	2-6	0-4	3-6
Hg	0-2	2-6	1-4	0-6
Pb	0-2	2-6	3-4	6-6
Zn	0-0	0-6	0-1	0-6
Cl	0-2	0-6	0-4	0-6
SO_4	1-2	0-6	4-4	6-6
TOC	2-2	3-6	2-4	1-6

* The first number indicates number of times standard was exceeded; the second number is sample population.

twice in the background groundwater of Phase II. The source of the lead has not been determined.

Sulfate data indicate a high background concentration of this contaminant. This level appeared to be the result of the oxidation of pyrite present in the soil. Total organic carbon showed the largest concentration at the first sampling and declined significantly thereafter. However, since TOC exceeded the standard five out of eight times, a slight contamination by organic species is suggested.

Downstream Groundwater--

The parameters that exceeded drinking water standards were the same as those found in the background groundwater, i.e., iron, mercury, lead, sulfate, and TOC. The degree of concentration levels, however, was elevated.

Although 50 percent of the samples exceeded the iron standard in Phase II, the concentrations were similar to those of background levels. The data suggest that iron leaching out of the fill was strongly attenuated by the soil matrix.

Mercury was present in trace amounts in the downstream groundwater. Based on the concentration trends observed in Phases I and II, it can be concluded that it did not contaminate the water in the downstream well.

Lead was present at elevated concentrations and exceeded the standard on nine out of ten occasions. Although the concentrations were not exceedingly high (a range from 0.02 to 1.8 ppm with an average of 0.28 ppm), observed trends clearly indicated contamination of the downstream groundwater. Whether the lead was indigenous or leached from the sludge during rainfall periods is not known.

The downstream groundwater was highly contaminated with sulfate. Concentrations ranged from 825 to 1,650 ppm with an average of 1,156 ppm. Since the sulfate levels in the leachates were low, these high sulfate concentrations were presumably due to the oxidation of pyrite (black shale) and intrusion of river water moving as subsurface water above the limestone hardpan.

Although TOC exceeded the standard three out of ten occasions, its levels in the downstream well were not greatly elevated (an average of 10.2 ppm). However, the data suggest that the clay soil did not completely prevent leachate migration from the site. As a result, a slight contamination of organics probably had occurred. This finding is also supported by the identification of fecal coliform and fecal streptococcus (10 and 30 colonies/100 ml) in the 7-22-77 sample.

In practicing trenching of sewage sludge at this site, the sludge was placed in trenches dug at depths of 3 to 4 m in a clay layer (5.5 to 6.0 m thick) overlying limestone bedrock. It took leachate less than 8 yr to pass through the clay layer and migrate over 30 m downstream along the clay-limestone interface. This was indicated by the contamination of sulfate, lead, and possibly iron, TOC, and fecal bacteria in the groundwater downstream. Oxidation of pyrite in the disposal area may result in lowering of the solution pH, thereby increasing the mobility of most heavy metals. However, some degree of soil attenuation of leachate and heavy metals was noted, although the extent of this attenuation was not determined. It was predicted that future monitoring would reveal similar or higher levels of contamination in the groundwater at this site.

SITE 5

Soil Analyses

During drilling of the in-refuse well, soil samples were taken from the refuse-soil interface (7.3 to 7.6 m), midway between soil and groundwater (9.1 m), and the soil-groundwater interface (11 to 11.3 m). These samples were extracted sequentially with water and concentrated nitric acid. The results are given in Table 32.

The largest concentrations of TOC, COD, and TKN were found at the soil-groundwater interface. The data suggest a significant downward movement of leachate into the groundwater supplies, as indicated by the TOC, COD, chloride, and sulfate trends. The concentrations of ammonium and nitrate were very low at all three soil depths.

Large portions of calcium and chromium at the refuse-soil interface (7.3 to 7.6 m) were soluble in water, whereas at lower depths they were present primarily in the acid extractable form. Except for iron, the other metals analyzed were only sparingly soluble in water. Significant movements of copper and iron to lower depths were suggested by the acid-extractable concentrations of these two metals. Concentrations of acid-extractable lead at the first two depths were quite high, and were greater than the lead levels (10 ppm) generally found in soils (1, 2). However, no significant migration of the element toward the groundwater was indicated by the soil analysis.

Sludge Analyses

Two grab sludge samples obtained from the sewage treatment plant during Phase I were sequentially extracted, first with water and then concentrated nitric acid. The results showed considerable variations in the concentrations of various constituents in the sludge between sampling dates (Table 32).

TABLE 32. ANALYTICAL RESULTS FOR SITE 5, PHASE I*

Constituent†	Soil Samples Taken Below Landfill During Drilling of In-Refuse Well Refuse-Soil Interface (7.3 to 7.6 m) 5/16/75 Water	 Acid	Midway Between Soil & Groundwater (9.1 m) 5/16/75 Water	 Acid	Soil-Groundwater Interface (11 to 11.3 m) 5/16/75 Water	 Acid
TOC	420		120		720	
COD	1198		160		2994	
TKN	12		16		29	
NH_4-N	3		4		3	
NO_3-N	<0.1		<0.1		0.3	
Cl	47		<10		32	
SO_4	183		75		123	
Ca	96	25	8	166	16	115
Cd	<0.01	0.11	<0.01	0.12	<0.01	0.05
Cr	1.80	<0.13	0.20	3.90	<0.20	2.88
Cu	0.50	3.25	1.00	29.25	<0.15	12.80
Fe	30	44416	67	8190	8	18844
Hg	0.002	0.110	<0.001	0.139	0.003	0.056
Pb	0.2	24.0	<0.2	15.5	<0.2	8.1

TABLE 32. (continued)

Constituent†	Sludge				Background Groundwater
	9/10/75		6/7/76		9/10/75
	Water	Acid	Water	Acid	
pH	7.7				6.8
Tot. Solids					258
TOC	687		25575		2
COD	2410				6
MBAS			0.49		
TKN	560				0.5
NH_4-N	429				0.3
Cl	584		450		8
SO_4	33		150		5
Ca	159	1955			2
Cd	0.03	2.83		1.5	<0.001
Cr	0.20	46.40		96	0.02
Cu	0.10	92.20		75	<0.01
Fe	17	92.60		13750	0.09
Hg	<0.001	0.011		0.011	0.001
Ni				5.1	
Pb	0.8	151		38	0.060
Zn				175	
Moisture, %	70.4		85		

TABLE 32. (continued)

Constituent†	Existing Offsite Well		Offsite Well (Shallow)			
	9/10/75	6/7/76	5/28/75	9/10/75	10/29/75	6/7/76
pH			6.7	6.8	Insufficient sample	
Tot. Solids			462	355		
TOC		12	300	8		16
COD			603	22		
MBAS		<0.01				<0.01
TKN	1.3		13.7	1.9		
NH_4-N	0.6		1.2	1.0		
NO_3-N	0.51		<0.02	1.68		
Cl	37	21	23	10		24
SO_4	32	33	11	3		30
Ca	24			2		
Cd	0.004	0.010	0.001	0.003		0.002
Cr	0.01	<0.01	0.02	0.02		<0.01
Cu	<0.006	<0.01	<0.006	0.008		0.01
Fe	0.31	23	1.98	0.39		32
Hg	<0.0002	<0.0002	0.002	<0.0002		<0.0002
Ni		<0.01				<0.01
Pb	0.028	0.009	<0.020	0.054		0.009
Zn		0.06				0.20

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* Soil and sludge were extracted with water and conc. nitric acid. Sampling dates are also indicated.

† Concentrations are expressed as mg/kg of dry soil, mg/kg of wet sludge, mg/l of groundwater or leachate.

Generally, when the data were compared to those reported by Sommers (9) for 250 sludge samples from 150 sewage treatment plants, the concentrations of the selected constituents (with the exception of iron) were within the ranges, but slightly less than the median concentrations reported.

The methylene blue-activated substances (MBAS) were present in insignificant quantities in the sludge. The data for fecal bacterial counts were inconclusive and, therefore, not reported.

Decomposition Gases In-Refuse Well

Gas samples taken at 0.9 m below the cover surface, and 1.5 m above the landfill bottom were analyzed for four major gas species (Table 33). Carbon dioxide and methane were the major gases found, followed by nitrogen and oxygen. Presence of nitrogen and oxygen were indications of sample buret leakage during shipment. There was no apparent trend in gas composition with sampling depths and dates.

Groundwater from Background and Off-Site Wells

Results from groundwater monitoring during Phases I and II are given in Table 32 and in Table 5 of Appendix E, respectively. Concentrations of the contaminants measured in the groundwater were generally lower in the background well than in the downstream off-site wells. This indicated proper placement of the background well.

There were seasonal variations in the groundwater contaminant levels (see Figures 76 and 77 for selected contaminants). Peak concentrations of contaminants occurred at different sampling dates. For example, during Phase II monitoring, TOC concentrations decreased steadily and iron concentrations fluctuated while decreasing over the 1-yr sampling period. The iron level in the downstream groundwater was 50 times greater than that in the background groundwater; iron from both sources greatly exceeded the EPA drinking water standard. Trends in changes in concentrations of TOC, sulfate, and chloride were similar in background and downstream groundwater (Figure 77).

When results from Phase I were compared with those of Phase II, the concentrations of various contaminants in the background groundwater from the two phases were similar, except for chloride, sulfate, iron, and TOC. However, cadmium, chromium, copper, iron, nickel, chloride, sulfate, and TOC concentrations in the downstream groundwater were higher in Phase II than in Phase I. Possibly, leachate emanating from the landfill continued to reach the groundwater.

TABLE 33. GAS COMPOSITION AT SITE 5 IN-REFUSE WELL

Gas Species	Sampling Date 5/28/75 Upper	5/28/75 Lower	9/10/75 Upper	9/10/75 Lower
	%			
CH_4	36.0	29.8	28.5	43.0
CO_2	49.2	37.5	67.2	50.4
O_2	3.3	7.3	0.7	1.1
N_2	11.5	25.4	3.6	5.4

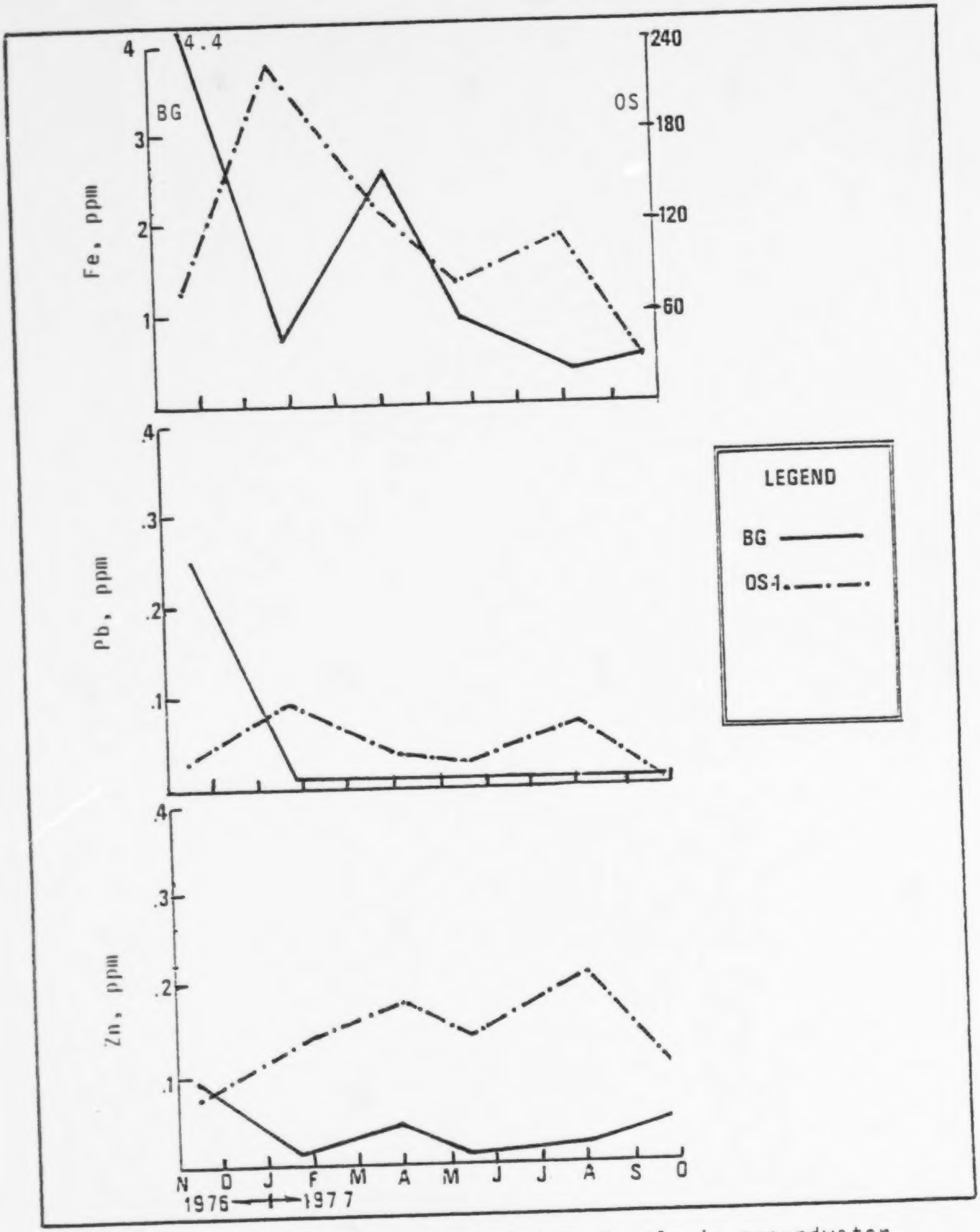

Figure 76. Fe, Pb, and Zn levels in groundwater. (Site 5)

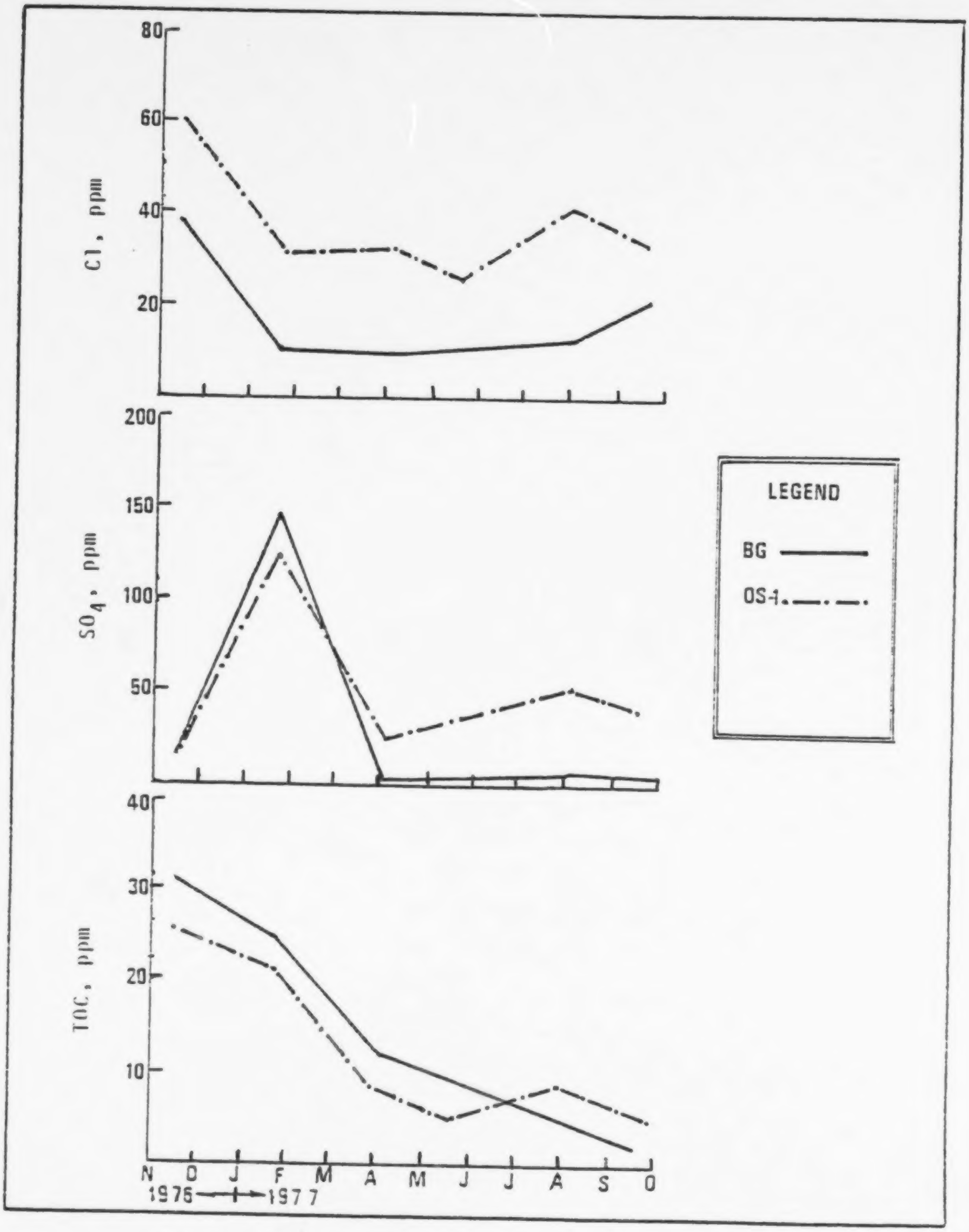

Figure 77. Cl, SO_4, and TOC levels in groundwater. (Site 5)

Environmental Impact Assessment

This disposal site receives large quantities of sewage sludge. With relatively high annual precipitation and numerous springheads within the disposal area, it is anticipated that the impact from sludge burial would be high. To place the possible degradation of groundwater quality in perspective, concentrations of various contaminants in the water are compared with EPA drinking water standards (Table 34).

Background Groundwater--

In the background groundwater, iron, mercury, lead, and TOC exceeded the drinking water standards one or more times. Although the standard for iron was exceeded six out of seven occasions, it was indicative of the high iron content that occurs naturally in the soil and/or water in this area.

Concentrations of mercury and lead exceeded the drinking water standards once and twice, respectively, on seven occasions. However, these elevated concentrations were not in line with other readings, which were near or below detection levels; contamination of background groundwater by these metals was not confirmed.

Total organic carbon was detected at high levels on the first two sampling dates in Phase II; however, these levels decreased significantly thereafter. There was no indication that the background groundwater was contaminated with leachate in the form of organic species. Some organic pollution is apparently present in the natural groundwater of this area.

Downstream Groundwater--

Concentrations of iron, lead, and TOC in the groundwater from downstream wells were found to exceed the drinking water standards 2 to 11 times during the project.

The iron concentrations were exceedingly high in the downstream groundwater. Despite the fact that the groundwater in the background well had a naturally high iron content, the disposal operation contributed significant additional amounts of iron to the groundwater.

Lead exceeded the drinking water standard in 3 out of 11 samples. In Phase II, these concentrations either exceeded (twice) or approached the drinking water standard. As a result, contamination of the groundwater with lead by the disposal operation was highly suspect.

Total organic carbon exceeded the drinking water standard on 5 out of 10 occasions. Since these concentrations decreased with sampling dates, and were in the same general range as the background level (Figure 77), it was believed that the landfill did not contribute significant organic pollution.

TABLE 34. NUMBER OF TIMES SAMPLED CONSTITUENT CONCENTRATIONS EXCEEDED EPA DRINKING WATER STANDARDS (SITE 5)

Constituent	Background Wells		Downstream Wells	
	Phase I	Phase II	Phase I	Phase II
Cd	0-1*	0-6	0-5	0-6
Cu	0-1	0-6	0-5	0-6
Fe	0-1	6-6	5-5	6-6
Hg	0-1	1-6	0-5	0-6
Pb	1-1	1-6	1-5	2-6
Zn	0-0	0-6	0-5	0-6
Cl	0-1	0-6	0-5	0-6
SO_4	0-1	0-6	0-5	0-6
TOC	0-1	3-6	3-4	2-6

* The first number indicates number of times standard was exceeded; the second number is simple population.

Overall, the results presented indicated that the landfill had not leached detectable amounts of cadmium, copper, mercury, or organic substances (as indicated by TOC). Leaching of substantial amounts of iron was occurring, however. This iron was probably from the buried sludge or clay material in the vicinity of the fill. The proximity of the downstream well to the edge of the disposal area (less than 30 m) could have resulted in the detection of higher levels of contaminants than would be detected at locations farther away from the site.

The impact on groundwater quality from landfilling of sewage sludge was less pronounced at this site as compared to other sites investigated. This site had been carefully selected following extensive geological surveys and detailed study. The operation and management at this site is claimed to be one of the best in the country. The majority of the leachate generated presumably moves through the soil strata and along the soil-shale interface, escaping as surface leachate emanations along the creek. Little of the leachate generated is expected to percolate deeper into the groundwater in the area.

SITE 6

Soil Analyses

Soil samples from the refuse-soil interface (6.1 to 6.7 m) and soil-groundwater interface (7.6 to 8.2 m) were sequentially extracted, first with water and then concentrated nitric acid. Results are given in Table 35.

Concentrations of TOC and COD were high at both depths, suggesting downward movement of organic substances and reduced chemical species from leachate. Except for sulfate and iron, the levels of water-soluble constituents measured in the upper depth were either similar or higher than those of the lower depth. Water-soluble mercury concentrations (0.140 and 0.038 ppm) were relatively high with respect to those in the acid-extractable form. Other heavy metals generally were only sparingly soluble in water. With the possible exception of lead (15 ppm), none of the chemical constituents analyzed were present in elevated levels in the acid extract. This suggests that concentrations of these constituents in the soil were not profoundly affected by the disposal operation.

Sludge Analysis

Two grab sludge samples obtained 1 yr apart from the sewage treatment plant were sequentially extracted with water and concentrated nitric acid (Table 35). Constituent concentrations in the two sludge samples differed considerably. The constituents analyzed fall within the concentration ranges found in data presented by Sommers (9). Except for iron and inorganic nitrogen,

TABLE 35. ANALYTICAL RESULTS FOR SITE 6, PHASE I*

Constituent†	Soil Samples Taken Below Landfill During Drilling of In-Refuse Well			
	Refuse-Soil Interface (6.1 to 6.7 m)		Soil-Groundwater Interface (7.6 to 8.2 m)	
	Water	Acid	Water	Acid
	5/28/75		5/28/75	
TOC	3000		2800	
COD	4792		3057	
TKN	78		20	
NH_4-N	62		17	
NO_3-N	1		1	
Cl	96		16	
SO_4	120		250	
Ca	103	176	73	162
Cd	<0.01	0.36	0.01	0.08
Cr	<0.20	<0.20	<0.20	<0.20
Cu	0.20	27.0	<0.10	4.8
Fe	2	2625	7	1187
Hg	0.140	0.640	0.038	0.426
Pb	<0.2	15.0	<0.2	9.3

TABLE 35. (continued)

Constituent†	Sludge				Background Groundwater	
	Water	Acid	Water	Acid		
	6/4/75		6/8/76		10/29/75	6/8/76
pH	5.5				6.1	
Tot. Solids					203	
TOC	587		13500		4	3.7
COD	937				9	
MBAS			14			<0.01
TKN	448				1	
NH_4-N	398				0.8	
NO_3-N	7				2.95	
Cl	123		1450		4	<2
SO_4	10		150		<1	<1
Ca	32	60			1	
Cd	0.04	0.12		0.12	<0.001	<0.001
Cr	1.88	3.75		225	<0.01	<0.01
Cu	0.20	11.2		36	0.010	0.69
Fe	4	181		1188	0.55	0.50
Hg	0.0004	0.002		<0.001	<0.0002	<0.0002
Ni				0.12		<0.01
Pb	0.5	2.6		6.2	0.026	<0.005
Zn				74		0.67
Moisture, %	98.5		95			

TABLE 35. (continued)

Constituent†	Offsite Well (Shallow)			
	5/28/75	9/11/75	10/29/75	6/8/76
pH	7.5	5.5	6.3	
Tot. Solids	148	52	126	
TOC		51	2	19
COD		116	11	
MBAS				<0.01
TKN		2.5	2.5	
NH_4-N		2.3	1.0	
NO_3-N		0.51	8.85	
Cl	26	41	5	5
SO_4	10	28	5	6.6
Ca	5	64	2	
Cd	<0.001	0.001	0.001	<0.001
Cr	<0.01	<0.01	0.02	<0.01
Cu	0.050	0.050	0.010	<0.01
Fe	3.85	1.57	0.10	0.25
Hg	0.003		0.0002	<0.0002
Ni				<0.01
Pb	0.060	0.025	0.04	<0.005
Zn				0.18

TABLE 35. (continued)

Constituent†	Offsite Well (Deep) 5/28/75	9/11/75	10/29/75	6/8/76
pH	7.5	5.0	6.5	
Tot. Solids	200	359	66	
TOC		11	2	9.4
COD		21	4	
MBAS				0.10
TKN		4.3	0.5	
NH_4-N		31	0.4	
NO_3-N		1.94	4.15	
Cl	7	6	5	11
SO_4	53	4	5	2.9
Ca	9	3	2	
Cd	0.002	0.002	<0.001	<0.001
Cr	<0.01	0.01	<0.01	<0.01
Cu	0.090	<0.006	0.010	<0.01
Fe	3.85	0.41	0.05	0.12
Hg	0.043	0.0002	<0.0002	<0.0002
Ni				<0.01
Pb	0.050	0.015	0.016	<0.005
Zn				0.07

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* Soil and sludge were extracted with water and conc. nitric acid. Sampling dates are also indicated.

† Concentrations are expressed as mg/kg of dry soil, mg/kg of wet sludge, mg/l of groundwater or leachate.

they were generally less than the median concentrations reported. None of the heavy metals were present in elevated concentrations in the sludges.

Decomposition Gases in In-Refuse Well

Gas samples taken at depths of from 0.9 m below the cover surface and 1.5 m above the landfill bottom were analyzed for four major gases (Table 36). Generally, 50 percent or more of the total volume was methane, and from 30 to 40 percent consisted of carbon dioxide. Nitrogen and oxygen were present, indicating sample buret leakage during shipment. The percentages of methane and carbon dioxide remained relatively constant during the three sampling dates.

Groundwater from Background and Off-Site Wells

Results from groundwater monitoring during Phases I and II are given in Table 35 and in Table 6 of Appendix E, respectively. It was speculated that the Phase I shallow well (OS-1 at 4.6 m) and deep well (OS-2 at 7.9 m) may not have intercepted leachate flow emanating from the fill. Thus, in Phase II an additional offsite well (OS-3) with three sampling depths (3, 8.5, and 17.1 m) was installed north of the landfill.

Background Groundwater--

The background groundwater, as measured in Phase I, contained higher concentrations of total solids and iron than the downstream groundwater sampled on October 29, 1975. There were also higher levels in the background groundwater of iron, copper, and zinc than in the downstream groundwater sampled on June 8, 1976. It was suspected that these contaminants may have come from the water pipes. Nevertheless, none of the contaminants in the background groundwater taken in June 1976 showed elevated concentrations, as most of the heavy metals were below detection limits.

Among the contaminants measured in Phase II, concentrations of iron and lead were lower in the project background groundwater than in the downstream groundwater (Figures 78 and 79). Other contaminant levels were largely similar in the background and downstream groundwaters. This would indicate proper location of the project background well.

The quality of the Phase I background groundwater was comparable to the groundwater taken from the project background well in Phase II. Except for the presence of iron, the quality of the groundwater from these two background wells appeared acceptable.

Downstream Groundwater--

During Phase I, there were considerable variations in contaminant levels in the downstream wells in the monitoring

TABLE 36. GAS COMPOSITION AT SITE 6 IN-REFUSE WELL

	Sampling Date					
	6/8/75		9/10/75		10/30/75	
Gas Species	Upper	Lower	Upper	Lower	Upper	Lower
	%					
CH_4	57.9	52.6	49.0	29.3	--*	58.7
CO_2	30.5	30.8	37.1	47.1	--	40.6
O_2	0.7	3.5	13.0	3.5	--	0.2
N_2	10.9	13.2	10.8	20.1	--	0.5

*Buret broken in transit

CM

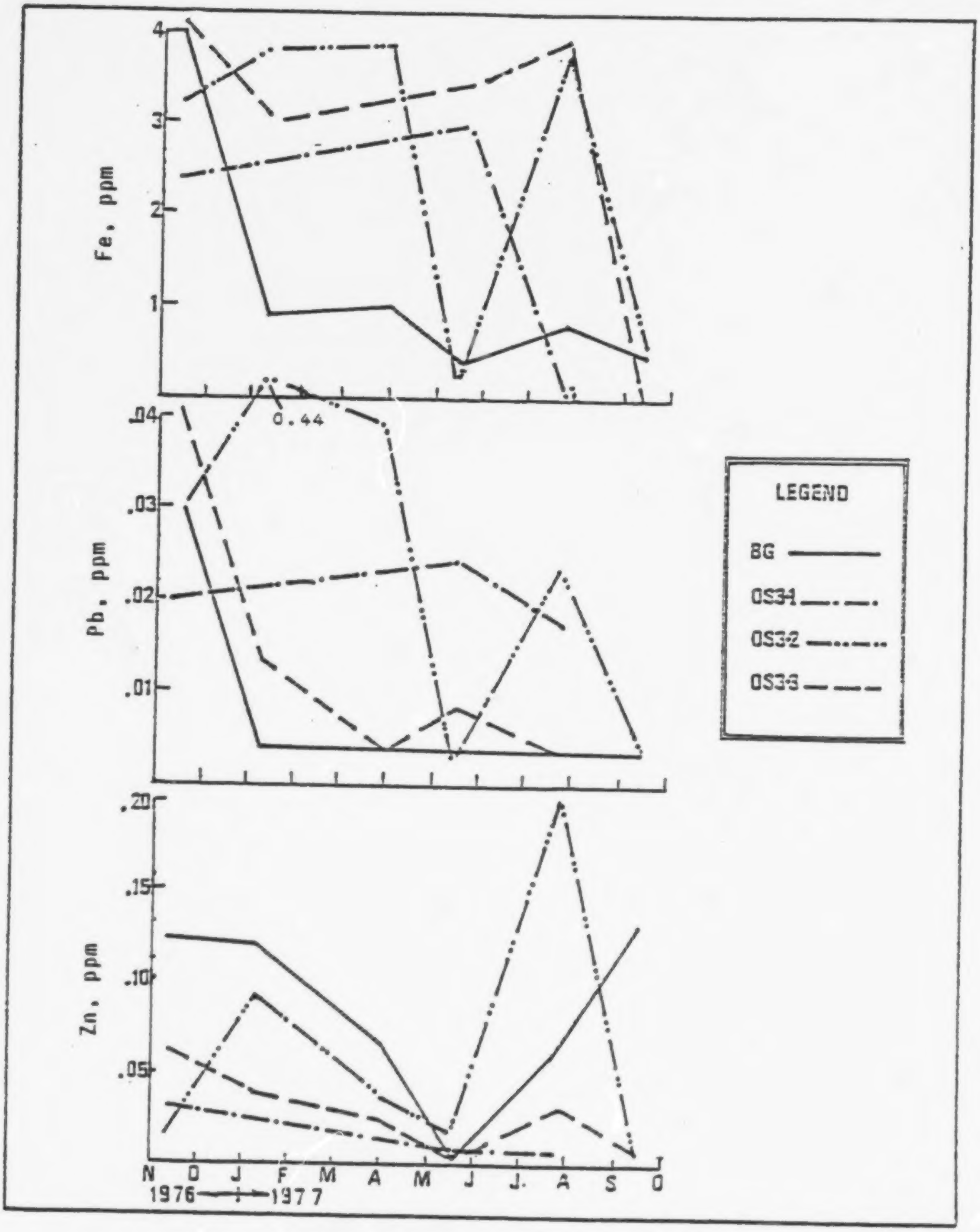

Figure 78. Fe, Pb, and Zn levels in groundwater. (Site 6)

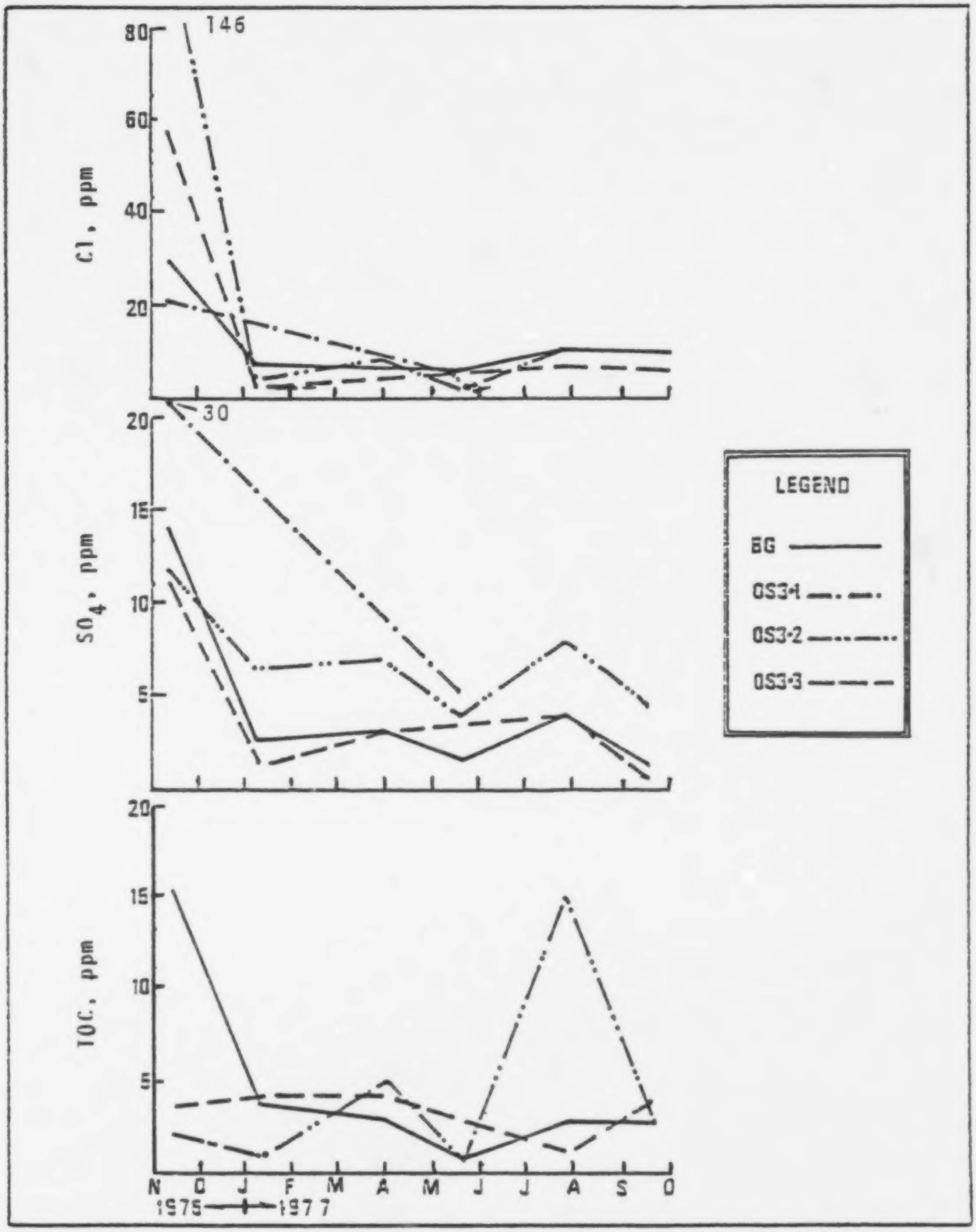

Figure 79. Cl, SO$_4$, and TOC levels in groundwater. (Site 6)

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period (Table 35). The lowest levels of these contaminants (primarily heavy metals) were found in the June 1976 samples. In the first and/or second samplings (May and September 1975), total solids, TOC, iron, mercury, and lead were present at slightly elevated concentrations in the downstream wells. Among the heavy metals in the downstream groundwater, there were consistently higher levels of lead from the deep well than from the shallow well. Differences in contaminant levels between the shallow and deep downstream wells generally decreased in the third and fourth samplings.

Concentrations of various contaminants in the downstream groundwater were not correlated with their levels in either the soils taken from the in-refuse well or the sludge from the treatment plant. This is expected considering soil attenuation and low contaminant concentrations in the soils or sludge.

During Phase II, TOC, sulfate, chloride, and iron levels in the groundwater were highest in the first samplings, possibly the result of water contamination with leachate and fill materials during drilling. There were considerable fluctuations of contaminant levels in the groundwater over the 1-yr sampling period (Figures 78 and 79). Peak concentrations of contaminants occurred at different sampling levels, depending on the contaminant measured. However, concentrations of lead, zinc, chloride, and TOC appeared to peak at the second sampling level in the OS-3 well. Overall, no discernible differences existed in concentrations of various contaminants in groundwater at the three levels.

Contaminant concentrations in the groundwater taken from the OS-1 and OS-2 wells in Phase II were similar to or lower than the concentrations found in Phase I. When contaminant levels in these two wells were compared with those in OS-3, it was noted that only iron and probably lead levels were consistently higher in the OS-3 well than either in OS-1 or OS-2. Other contaminant levels were about the same in the three off-site wells. This would suggest that the groundwater intercepted at these wells was of similar quality. Since the contaminant levels were low, it is possible that the off-site wells may have missed the leachate plumes.

Envirormental Impact Assessment

In evaluating the groundwater quality, the concentrations of selected parameters were compared with EPA drinking water standards. Results suggested contamination by iron to the groundwater from background and downstream wells. Probable contamination of the downstream wells with mercury, lead, and organic substances (TOC) was also indicated (Table 37).

TABLE 37. NUMBER OF TIMES SAMPLED CONSTITUENT CONCENTRATIONS EXCEEDED EPA DRINKING WATER STANDARDS (SITE 6)

Constituent	Background Wells		Downstream Wells	
	Phase I	Phase II	Phase I	Phase II
Cd	0-2*	0-6	0-8	0-21
Cu	0-2	0-6	0-8	0-21
Fe	2-2	6-6	4-8	14-21
Hg	0-2	0-6	2-7	1-21
Pb	0-2	0-6	1-8	0-21
Zn	0-1	0-6	0-2	0-21
Cl	0-2	0-6	0-8	0-19
SO_4	0-2	0-6	0-8	0-19
TOC	0-2	1-6	2-6	1-18

* The first number indicates number of times standard was exceeded; the second number is sample population.

The standard for iron was exceeded in all eight background groundwater samples, indicating that groundwater in the vicinity of the landfill had a naturally high concentration of the metal. The standard for iron was also exceeded in 18 out of 25 samples taken from the downstream wells. It appeared that iron levels were greater in the groundwater north of the fill area (OS-3) than they were south of it (OS-1 and OS-2). These differences were attributed to soil inhomogeneity existing at the disposal site.

Generally, mercury was not present in background groundwater as readings were below the minimum detection limit on all occasions. Concentrations of mercury exceeded the standard in three of 28 samples from the downstream wells, two occurring in groundwater south of the fill (Phase I) and one in groundwater north of the fill (Phase II). Since the three readings were inconsistent with most other downstream well readings, which were usually below detection limit, the landfill did not appear to be leaching mercury into the groundwater north or south of the fill area.

Lead in the background groundwater did not exceed the standard on any occasion in eight samples. It was generally not present in the natural groundwater as readings were at or below the detection limit on all but one occasion. The standard for lead was exceeded once in 28 samples of downstream groundwater when a high reading was recorded in the shallow well groundwater south of the fill area. However, readings generally showed consistent and well-defined increases in downstream groundwater north of the fill when compared to the lead levels in background groundwater. Thus, lead contamination in the groundwater intercepted by the north off-site well (OS-3) may have occurred.

Total organic carbon (TOC) exceeded the standard once in six samples of the background groundwater and three times in 24 samples of downstream groundwater. Due to the consistently low TOC levels in the background and downstream wells, there was no clear indication that these wells were contaminated by organic compounds migrating from the landfill.

Using the EPA drinking water standards, there were no clear indications that the groundwater has been contaminated with soluble salts, organic substances, or heavy metals. Data evaluation was impaired by the land of landfill leachate data and inconclusive fecal bacterial counts obtained in Phase I (data not shown). No apparent increase was detected for the selected contaminants when comparing background groundwater readings to those for downstream groundwater readings. Increases in iron concentration were observed in the downstream groundwater to the north of the site, and this was probably due to soil characteristics rather than the result of the disposal operation.

Lead did not usually exceed the standard, but small, well-defined increases in its levels were observed in the downstream groundwater.

Copious quantities of septic tank pumpings from resorts, which previously were discharged to the ocean, have been buried since 1972-73 in township landfills along the coast. However, state-mandated monitoring wells outside the disposal area or along the property boundary line have repeatedly failed to show any evidence of leachate contamination at many landfill sites. It is apparent that wells in such areas are incapable of detecting leachate. It is speculated that the leachate at this site is sinking deep into the groundwater and moving along as concentrated leachate plumes. Because of the locations of the project off-site wells and inadequate sampling frequency, these plumes have been relatively undetected throughout the course of the investigation. As evidenced by study results at Sites 1 and 3, leachate plumes may not be traveling laterally along the soil-groundwater interface. It is suggested that one way to detect this leachate would be to establish multiple depth groundwater monitoring wells immediately underneath the disposal area.

Soil attenuation of contaminants cannot be adequately assessed due to the lack of leachate data. However, some degree of attenuation usually occurs in soils. Because of the coarse-textured soils in the disposal area, significant migration of contaminants to lower depths could be expected. This is impounded by the tremendous quantities of septic tank pumpings and sewage sludge going into the landfill. Thus, although the monitoring results are inconclusive, it is speculated that considerable contamination of the groundwater at the landfill area has occurred.

SITE 7

Soil Analyses

Soil samples taken at the refuse-soil interface (at 7.6 m) and soil-groundwater interface (at 10.7 m) were sequentially extracted, first with water and then concentrated nitric acid (Table 38). The results showed that TOC, COD, TKN, ammonium, chloride, sulfate, and water-soluble chromium and lead were higher at the shallower depth. Vertical movement of these constituents has apparently been limited by soil attenuation.

The concentrations of water-soluble chromium, copper, iron, and lead were very high in the soil at the 7.6-m depth. These metals may be associated with the high TOC and COD in the soil solution, and are probably indicative of the quality of the sludge buried at this site. Although the concentrations of chromium, copper, iron, and lead were lower than those typically found in soils (1, 2), an unusually large proportion of these metals was present in the water-soluble form. Except for iron, this was unexpected as the highly reducing conditions in soil

TABLE 38. ANALYTICAL RESULTS FOR SITE 7, PHASE I*

Constituent†	Soil Samples Taken Below Landfill During Drilling of In-Refuse Well Refuse-Soil Interface (7.6 m) 7/31/75 Water	 Acid	 Soil-Groundwater Interface (10.7 m) 7/31/75 Water	 Acid
TOC	1300		675	
COD	3631		1996	
TKN	175		38	
NH_4-N	160		5	
NO_3-N	<1		33	
Cl	406		62	
SO_4	55		<20	
Ca	118	12	2056	27750
Cd	0.04	0.25	0.04	0.26
Cr	1.19	4.52	0.63	4.32
Cu	5.00	3.82	7.86	4.36
Fe	76	2889	180	3156
Hg	0.002	0.005	0.003	0.002
Pb	4.2	9.1	0.5	3.7

TABLE 38. (continued)

Constituent[†]	Sludge[#] Water 7/31/75	Sludge[#] Acid 7/31/75	Sludge[#] Water 6/8/76	Sludge[#] Acid 6/8/76	Background Groundwater 7/31/75
pH					
Tot. Solids					
TOC	5000		116740		7
COD	32096				6
MBAS			15		
TKN	1490				0.1
NH_4-N	821				0.1
NO_3-N	4				8.7
Cl	340		1900		5
SO_4	90		2375		3
Ca	3778	30600			79
Cd	0.81	15.07		1.1	<0.001
Cr	628	8975		18750	<0.01
Cu	11.50	37.50		49	0.360
Fe	145	1511		3000	0.42
Hg	0.011	0.003		<0.01	<0.0002
Ni				5.4	
Pb	25.0	284		338	0.030
Zn				106	

TABLE 38. (continued)

Constituent†	Offsite Well (Shallow)			
	9/18/75	10/2/75	11/4/75	6/8/76
pH	7.6		8.0	
Tot. Solids	4263		3511	
TOC	82	89	30	17
COD	127	195	37	
MBAS				0.26
TKN	51.4	38.0	47.6	
NH_4-N	38.8	33.0	47.6	
NO_3-N	0.02	0.59	1.10	
Cl	4	133	143	127
SO_4	12	18	13	16
Ca	83	59	88	
Cd	0.001	0.002	<0.001	0.002
Cr	0.01	0.25	0.04	0.01
Cu	0.010	0.030	0.020	<0.01
Fe	1.31	6.25	5.28	4.9
Hg	<0.0002	0.0002	0.0002	<0.0002
Ni				0.01
Pb	0.018	0.020	<0.010	<0.005
Zn				0.20

TABLE 38. (continued)

	Offsite Well (Deep)			
Constituent †	9/18/75	10/2/75	11/14/75	6/8/76
pH	7.9	8.1	8.2	
Tot. Solids	427	1630	396	
TOC	67	60	88	26
COD	135	141	110	
MBAS				<0.01
TKN	18.1	16.7	16.0	
NH_4-N	17.9	15.1	14.4	
NO_3-N	<0.02	0.78	1.0	
Cl	61	75	68	52
SO_4	21	24	22	9.1
Ca	67	52	63	
Cd	0.002	0.003	0.002	0.007
Cr	<0.01	<0.01	0.02	0.01
Cu	0.016	0.016	0.020	0.01
Fe	0.17	0.15	2.09	0.88
Hg	<0.0002	0.0002	<0.0002	<0.0002
Ni				0.24
Pb	0.052	<0.010	0.010	0.012
Zn				0.70

* Soil and sludge were extracted with water and conc. nitric acid. Sampling dates are also indicated.

† Concentrations are expressed as mg/kg of dry soil, mg/kg of wet sludge, mg/l of groundwater or leachate.

# Moisture content was 49% for the 6/8/76 sample.

under the fill would have precipitated these metals out as sulfides, rendering them sparingly soluble in the soil solution.

Sludge Analyses

Results of the sequential extraction of the grab sludge samples obtained from the sewage treatment plant are presented in Table 38. It is difficult to compare the sludge data, since no moisture percentage was reported for the sample obtained in 1975. Presumably, the sample with 49 percent moisture had a lower moisture content than did the 1975 sample. There were considerable variations between the two samples in constituent concentrations (wet weight basis).

Concentrations of copper, iron, lead, and particularly chromium in the 1975 sludge were very high in the water-soluble fraction. This is consistent with the observations made of these metals in the soil at the refuse soil interface. Except for chromium and lead, the constituents measured in the sludge in both years were generally within the ranges, but less than the median concentrations reported by Sommers (9). Chromium contents greatly exceeded the median concentration (890 ppm), while those of lead were only slightly higher than the median (500 ppm). The high levels of these two metals, especially those of chromium, probably were due to the discharge of wastewater from the leather tanning and finishing industries.

Leachate Analyses

The leachates collected during Phases I and II were analyzed for the same constituents as were those in the groundwater samples. Results are shown in Table 39. The pH, total solids, TKN, ammonium chloride, and lead showed relatively small changes in concentrations over the three sampling dates in 1975. Concentrations of the selected constituents in the June 1976 sample were generally either close to or lower than the corresponding 1975 levels. None of the heavy metals in the Phase I leachate were found at elevated concentrations.

The leachate analyses for Phase II showed constituent concentrations that were close to and/or below the concentrations found in Phase I. Constituents showing significant decreases were chromium, iron, lead, chloride, and TOC. Reasons for the decline in levels of these constituents in the leachates are unknown; it may be due to failure to intercept the concentration centroids of the leachate plumes or actual dilution of the generated leachate volumes.

TABLE 39. CHEMICAL ANALYSIS OF LEACHATES FROM IN-REFUSE WELL (SITE 7)

	Phase I			
Constituent*	9/18/75	10/2/75	11/4/75	6/8/76
pH	7.5	7.7	7.6	
Tot. Solids	4413	3770	3736	
TOC	1083	1333	733	118
COD	2736	4505	1345	
MBAS				<0.01
TKN	544	555	510	
NH_4-N	521	517	482	
NO_3-N	0.03	0.11	0.12	
Cl	1090	1283	1123	1000
SO_4	<1	<1	<1	<1
Ca	164	198	115	
Cd	0.011	0.011	0.006	<0.001
Cr	0.14	2.93	1.91	0.05
Cu	0.040	0.063	0.130	0.02
Fe	96	126	104	1.1
Hg	0.0007	0.0002	0.0002	<0.0002
Ni				0.04
Pb	0.364	0.264	0.340	0.03
Zn				0.06

TABLE 39. (Continued)

Constituent*	Phase II					
	11/12/76	1/11/77	3/31/77	5/18/77	7/26/77	9/19/77
Cd	<0.001	0.010	<0.005	0.010	<0.005	0.005
Cr	0.03	0.12	0.08	<0.01	0.08	0.15
Cu	<0.01	0.03	0.03	0.04	0.01	0.05
Fe	1.60	9.40	4.70	6.00	2.70	7.80
Hg	<0.0002	<0.0002	0.002	0.0011	0.0002	0.0008
Ni	0.01	0.06	0.05	0.11	0.12	0.15
Pb	0.005	0.060	0.050	0.020	0.250	0.040
Zn	0.19	0.26	0.14	0.06	0.08	0.15
Cl	36	5	3	3	26	423
SO_4	1	1	6	10	15	1
TOC	184	78	395	69	59	94
Sp. Cond.	4115	--[†]	--	4400	--	10000

[*] Specific conductance in µmhos/cm, all other constituents concentrations in ppm.

[†] Insufficient sample.

Decomposition Gases in In-Refuse Well

Gas samples collected from two different depths during Phase II were analyzed for four decomposition gases (Table 40). Although the data were incomplete, averages of the second and third sampling results indicated that the volumes of methane, carbon dioxide, nitrogen, and oxygen were 50.8, 26.2, 17.7, and 5.4, respectively. Changes in concentrations of the four gases with sampling depth and date were not confirmed due to missing data.

Groundwater Analyses

Background water samples were obtained from a private well (Phase I) and a project background well (Phase II). Downstream groundwater samples were taken from two off-site wells (OS-1 and OS-2 at depths of 6.7 and 9.8 m, respectively) during Phase I and Phase II, and also from a deeper off-site well (OS-3 at 13.7 m) installed in Phase II. Groundwater monitoring results obtained during Phases I and II are given in Table 38 and in Table 7 of Appendix E, respectively.

With the exception of copper, lead, and nitrate, contaminant concentrations during 1975 were generally lower in the background groundwater in comparison to those in the groundwater from downstream wells. While nitrate was slightly elevated, copper and lead concentrations in the background groundwater were within the ranges of most terrestrial waters (4).

There were wide fluctuations in contaminant concentrations by sampling date and level (Figures 80 and 81). During Phase I, the contaminants analyzed from the June 1975 sample showed overall lower levels than those in the 1975 samples (Table 38). In addition, concentrations of total solids, TOC, MBAS, TKN, ammonium, chloride, cadmium, and iron were, for the most part, higher in the shallow well than in the deep well. This differential impact on the groundwater was also found later in Phase II. Although chromium and lead were present at elevated concentrations in the sludge and in a water-soluble form in the soil at the refuse-soil interface, the concentrations of these metals in the downstream groundwater were low, sometimes below detection limits.

Groundwater collected from the project background well in Phase II monitoring contained low levels of all contaminants, excepting iron. Concentrations of cadmium, chromium, copper, nickel, and lead were generally below detection limits. When compared to the downstream groundwater, contaminant levels in the background groundwater were generally lower than those in the groundwater from the three off-site wells (Table 7 of Appendix E and Figures 80 and 81).

TABLE 40. CHANGES IN GAS COMPOSITION IN IN-REFUSE WELL AT TWO DEPTHS FROM SITE 7

Gas Species	9/18/75 Upper	9/18/75 Lower	10/2/75 Upper	10/2/75 Lower	11/14/75 Upper	11/14/75 Lower
	%					
CH_4	5.5	--*	--†	53.6	48.0	--*
CO_2	18.8	--	--	32.4	20.0	--
O_2	6.2	--	--	3.3	7.4	--
N_2	69.5	--	--	10.7	24.6	--

*Air contaminated sample

†Buret broken in transit

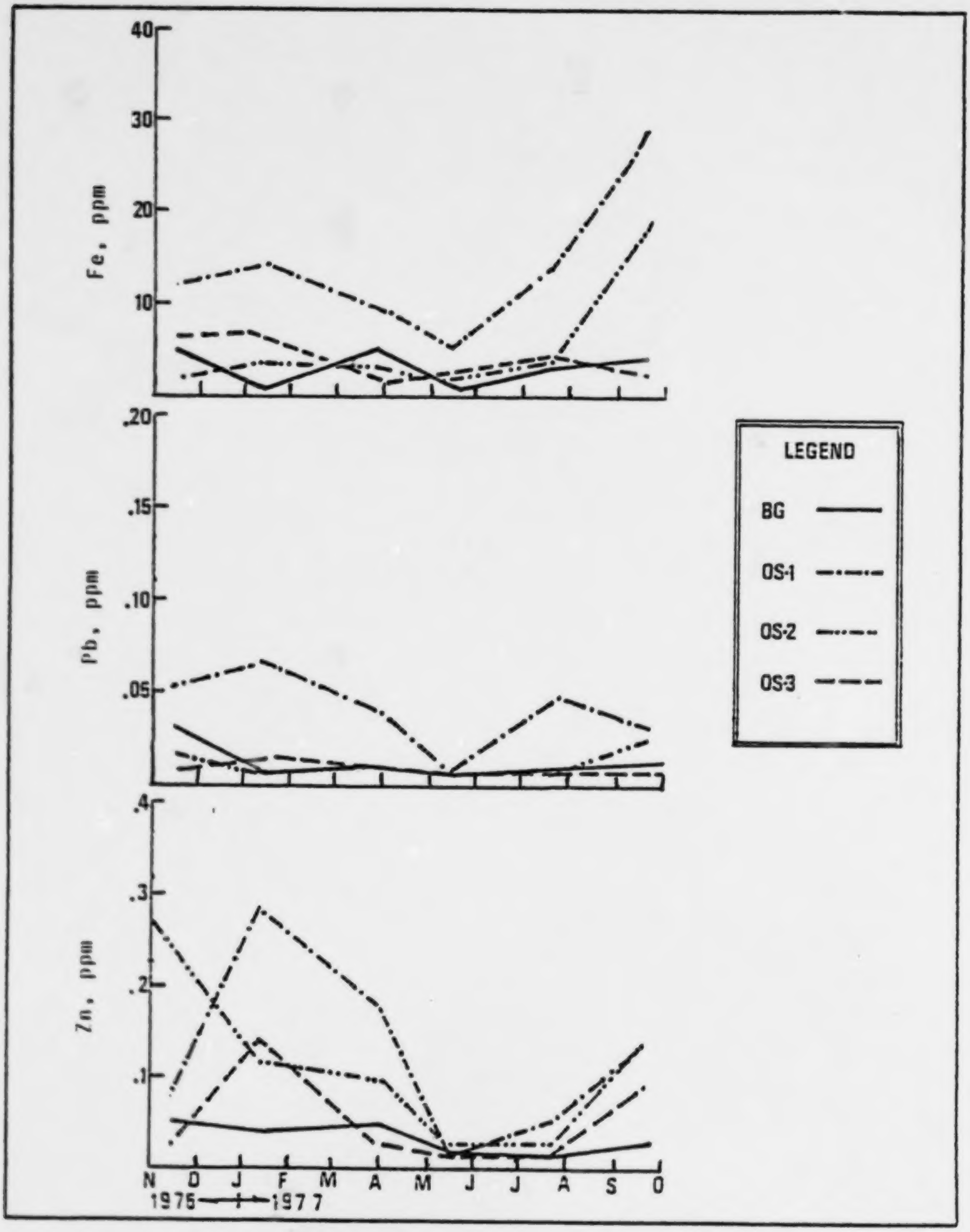

Figure 80. Fe, Pb, and Zn levels in groundwater. (Site 7)

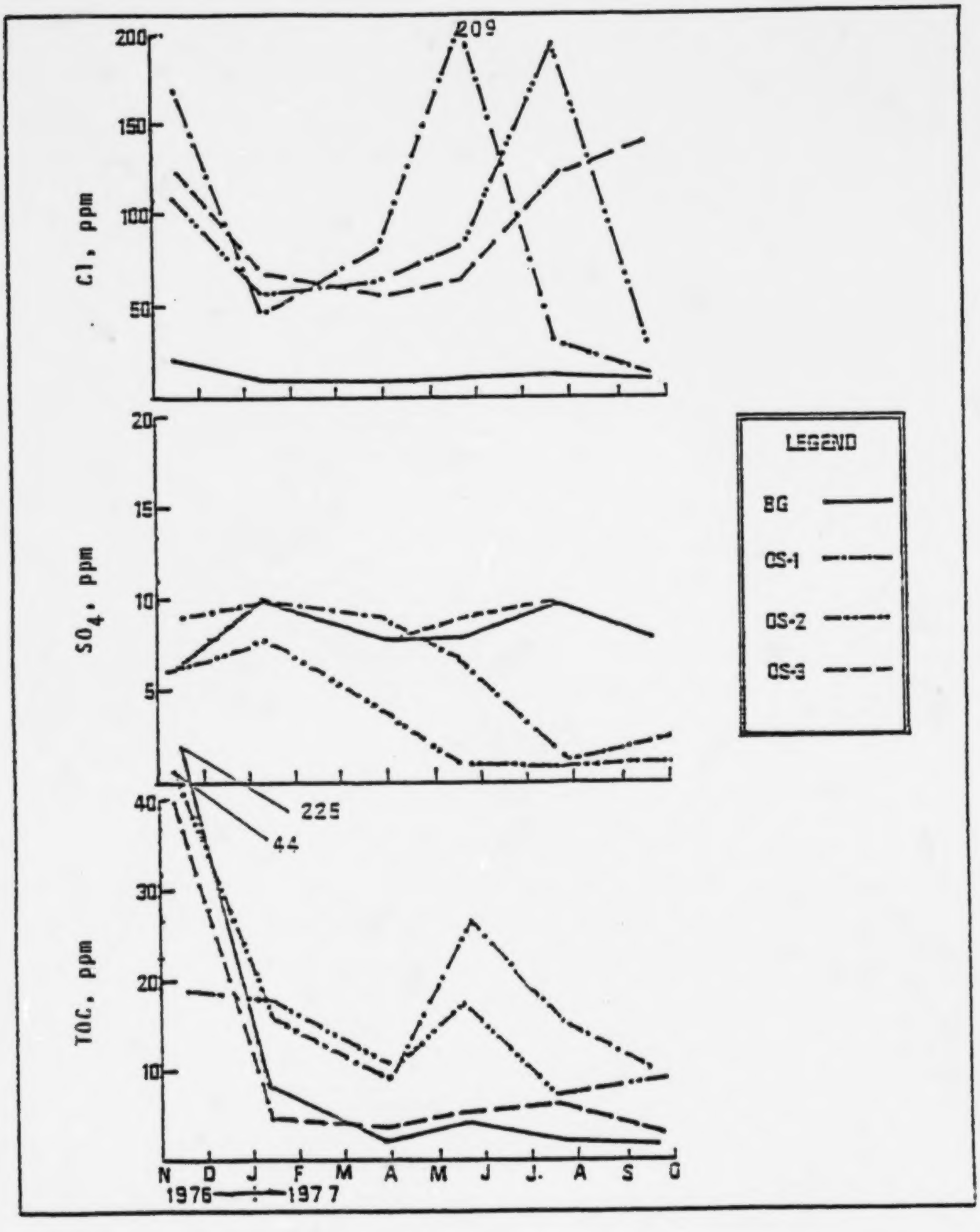

Figure 81. Cl, SO$_4$, and TOC levels in groundwater. (Site 7)

While chloride and sulfate concentrations remained relatively constant in the downstream groundwater regardless of sampling depth, concentrations of iron, nickel, lead, zinc, and TOC appeared to be consistently higher in the groundwater from the shallow well (OS-1) than from the deeper wells (OS-2 and OS-3). Except for iron and possibly TOC, contaminant levels in the downstream groundwater were generally low. Again, the high chromium and lead levels in the sludge seemingly had no adverse effects on groundwater quality beneath the landfill. However, there were indications of leachate movement in the form of organic substances into the shallow groundwater, as shown by the TOC levels in OS-1.

Results of bacteriologic examination indicated the presence of pollution in the form of both fecal coliform and fecal streptococcus at OS-1 and OS-2 wells (Table 41). Fecal coliform counts of fecal streptococcus showed possible contamination of both wells. This partially substantiates the TOC findings, i.e., the passage of some organic pollution through the shallow groundwater was indicated.

Environmental Impact Assessment

The residents in the vicinity of the disposal area were primarily concerned with the possible degradation of the well-water supply. To determine the water quality, concentrations of various parameters in the groundwater were compared with the EPA drinking water standards (Table 42). In addition, evaluations of fecal bacterial counts were also included.

Background Groundwater--

Except for iron, which greatly exceeded the standards seven out of seven times, the quality of the background groundwater in Phases I and II appeared to be good. Although the acid-extractable iron concentrations in the soil at the disposal site were not high, there were considerable amounts present in the water-soluble form that contributed to high levels of iron in the background groundwater.

Downstream Groundwater--

The contaminants in the downstream groundwater with concentrations exceeding drinking water standards were iron, TOC, mercury, and lead (Table 42).

Iron levels exceeded the standard 22 out of 26 times in downstream wells, which is not surprising since its levels in the background well were exceedingly high. This indicated that most of this metal detected in the downstream wells was probably background level rather than due to the disposal operation. Concentrations of iron detected in the deeper downstream wells

TABLE 41. BACTERIOLOGIC EXAMINATION OF GROUNDWATER FROM OFF-SITE WELLS (SITE 7)*

Well	Fecal Coliform	Fecal Streptococcus
	colonies/100 mℓ	colonies/100 mℓ
OS-1	4	23
	< 3	23
	< 3	4
OS-2	< 3	23
	3	7
	3	15

*7-29-77 sample

TABLE 42. NUMBER OF TIMES SAMPLED CONSTITUENT CONCENTRATIONS EXCEEDED EPA DRINKING WATER STANDARDS (SITE 7)

Constituent	Background Wells		Downstream Wells	
	Phase I	Phase II	Phase I	Phase II
Cd	0-1*	0-6	0-8	0-18
Cu	0-1	0-6	0-8	0-18
Fe	1-1	6-6	6-8	18-18
Hg	0-1	0-6	0-8	1-18
Pb	0-1	0-6	1-8	1-18
Zn	0-0	0-5	0-2	0-18
Cl	0-1	0-6	0-8	0-18
SO_4	0-1	0-6	0-8	0-18
TOC	0-1	1-6	8-8	8-18

* The first number indicates number of times standard was exceeded; the second number is sample population.

(OS-2 and OS-3) averaged approximately the same as those in the background well samples. However, leaching of iron from the fill was noted, since iron levels in the shallow well (OS-1) were slightly, yet consistently, above those in the background well. This indicated that the shallow groundwater intercepted iron leaching from the fill.

Mercury levels generally showed small but perceptible increases when comparing groundwater in the downstream wells to background groundwater. However, mercury contamination is not suspected since high mercury contents were not noted in the sludge or soil and the standard for this element was only exceeded one out of 26 times in the downstream wells.

Lead was present in relatively high concentrations in the sludge. This was also reflected in the leachate and the shallow groundwater downstream from the landfill. Although the shallow groundwater only exceeded the standard for lead on one occasion, the levels in this well were consistently higher than those in the background groundwater. This lead, however, had not moved to deeper layers in the groundwater.

Chloride concentrations in downstream groundwater did not exceed the standard in 26 samples. However, these concentrations showed significant increases on all occasions when compared to background groundwater, and the standard was approached on numerous occasions.

The standard for TOC concentrations was exceeded 16 out of 26 times in the downstream wells, primarily at the OS-1 and OS-2 wells. Therefore, contamination of the downstream groundwater in the form of organic compounds had occurred. These compounds migrated through the shallower groundwater, and apparently had not reached the groundwater intercepted by the deep well (OS-3). Fecal streptococcus was detected in the OS-1 and OS-2 wells, but the concentrations had not reached the point that the water was considered unsafe to drink. More work is needed to substantiate this finding.

Overall, the data indicate some degree of groundwater contamination by the disposal operation has occurred, as shown by the increased concentrations of chloride, TOC, iron, and lead in the downstream groundwater. Although some of these contaminants did not exceed the standards on all occasions, significant increases in their respective levels were noted on all occasions when compared to background groundwater.

The high contents of chromium in the sludge did not result in corresponding high levels in soil or groundwater. Concentrations of other heavy metals (cadmium, copper, nickel, zinc, and mercury) in the groundwater were not elevated as a result of the sludge disposal operation.

Although the soils at this site are relatively coarse-textured and large concentrations of heavy metals present immediately below the fill were in the water-soluble form, no significant migration of these metals was noted. Based on the locations of the downstream wells, fecal bacteria had traveled horizontally a distance of more than 20 m in the groundwater. The practice of subsurface disposal of sludge at this site has had a minimal impact on the groundwater quality. Further analysis of groundwater for fecal bacteria is needed to substantiate the data obtained in this study.

SITE 8

Soil Analyses

While drilling the in-refuse well, soil samples were taken from the refuse-soil interface (2.4 to 2.7 m), midway between the fill and groundwater (3 m), and from the soil-groundwater interface (3.4 to 3.7 m). These samples were sequentially extracted, first with water and then concentrated nitric acid. The results are presented in Table 43.

The soils at this site are coarse textured, moderately acidic (pH 5.3 to 6.0), and have a shallow water table (which fluctuated, but generally was at a depth of less than 3.7 m). The analytical results show that leachate from the landfill has migrated to a depth of 3 m, as indicated by the TOC, COD, and TKN levels. The nitrogen was present primarily in the organic form, since ammonium made up only 3.1 to 19 percent of TKN concentrations.

Chloride, and especially water-soluble calcium and iron, decreased rapidly with increasing soil depth. Large amounts of calcium were present in the water-soluble form, which may be related, in part, to the acidic nature of the soil. Concentrations of chloride, sulfate, and heavy metals were low when compared to those typically found in soils (1, 2). Although the soil is well-drained and acidic, no significant migrations of heavy metals were noted.

Large amounts of lead at the soil-groundwater interface were found in the water-soluble form (2.9 ppm). Its origin cannot be identified by the data obtained in this study. Nevertheless, it is possible that this water-soluble lead might have contributed to the high lead levels found in the downstream wells.

Sludge Analyses

Two grab sludge samples obtained from the sewage treatment plant during Phase I monitoring were sequentially extracted by water and concentrated nitric acid. Results showed that concentrations of the various constituents, including heavy metals

TABLE 43. ANALYTICAL RESULTS FOR SITE 8, PHASE I*

Constituent†	Soil Samples Taken Below Landfill During Drilling of In-Refuse Well					
	Refuse-Soil Interface (2.4 to 2.7 m)		Midway Between Soil & Groundwater (3 m)		Soil-Groundwater Interface (3.4 to 3.7 m)	
	Water	Acid	Water	Acid	Water	Acid
	6/30/75		6/30/75		6/30/75	
pH	5.5		6.0		5.3	
TOC	1350		3800		1360	
COD	6103		13545		4909	
TKN	288		602		199	
NH_4-N	9		115		25	
NO_3-N	2.6		2.8		1.9	
Cl	48		42		24	
SO_4	<10		<10		<10	
Ca	230	40	102	111	89	95
Cd	0.03	0.07	0.01	0.08	0.01	0.07
Cr	0.20	1.60	0.07	2.08	<0.07	1.63
Cu	0.40	3.06	0.40	4.90	0.14	3.00
Fe	138	1440	19	1140	1	1324
Hg	0.019	0.232	0.020	0.264	0.027	0.022
Pb	0.4	2.6	0.1	2.5	2.9	2.4
Moisture, %	12.3		23.3		15.0	

TABLE 43. (continued)

Constituent	Sludge Water 6/30/75	Sludge Acid 6/30/75	Sludge Water 6/8/76	Sludge Acid 6/8/76	Background Groundwater 9/17/75
pH	7.1				
Tot. Solids					
TOC	4200		33300		31
COD	9135				95
MBAS			5.6		
TKN	408				0.6
NH_4-N	76				
NO_3-N	0.4				
Cl	48		13		2
SO_4	17		63		25
Ca	133	127			46
Cd	0.01	0.12		0.12	0.002
Cr	0.12	1.73		1050	<0.01
Cu	0.40	31.00		44	0.090
Fe	10	116		538	0.50
Hg	0.024	0.229		<0.003	0.0004
Ni				3.0	
Pb	0.2	3.6		24	0.080
Zn				75	
Moisture, %	86.7			83.0	

TABLE 43. (continued)

Constituent†	Offsite Well (Shallow) 7/30/75	9/17/75	10/3/75	6/9/76
pH	7.5	7.8	8.2	
Tot. Solids	156	197	108	
TOC	320	38	50	29
COD	2698	91	66	
MBAS				<0.01
TKN	89	6.3	8.0	
NH_4-N	7.3	5.5	7.7	
NO_3-N	1.10	<0.02	0.62	
Cl	12	15	17	
SO_4	7	17	10	
Ca	907	77	77	
Cd	0.040	0.002	0.001	0.001
Cr	0.92	<0.01	0.19	<0.01
Cu	3.000	0.029	0.016	<0.01
Fe	114	0.70	8.38	27
Hg	<0.0002	0.0006	0.001	<0.0002
Ni				0.02
Pb	1.150	0.090	0.024	0.5
Zn				0.48

TABLE 43. (continued)

	Offsite Well (Deep)			
Constituent[†]	7/30/75	9/17/75	10/3/75	6/9/76
pH	7.0	7.8	7.8	
Tot. Solids	55534	32890	2170	
TOC	49	64	36	28
COD	83	135	104	
MBAS				0.02
TKN	1.4	6.2	1.3	
NH_4-N	0.8	0.7	0.3	
NO_3-N	0.20	<0.02	0.67	
Cl	4	9	10	10
SO_4	15	14	6	1.7
Ca	14	15	16	
Cd	<0.002	0.003	<0.001	0.001
Cr	<0.01	<0.01	<0.01	<0.01
Cu	0.430	0.009	0.018	<0.01
Fe	0.46	0.38	0.30	1.7
Hg	<0.0002	0.0008	0.001	<0.0002
Ni				<0.01
Pb	0.050	0.231	0.024	0.02
Zn				0.15

* Soil and sludge were extracted with water and conc. nitric acid. Sampling dates are also indicated.

† Concentrations are expressed as mg/kg of dry soil, mg/kg of wet sludge, mg/l of groundwater or leachate.

in the 1975 sample, were generally lower than those found in 1976 (Table 43). Concentrations of the chemical constituents in the two sludge samples were within the ranges, but less than the median concentrations reported by Sommers (9). The chromium concentration in the 1976 sample was exceedingly high (6,176 ppm on a dry weight basis). The source of this element is unknown. Based on preliminary results of the sludge analysis, local industries discharging wastewater to the sewer have not adversely affected the quality of the sludge generated at the treatment plant.

Leachate Analyses

The leachates collected from the in-refuse well during Phases I and II were analyzed for selected chemical constituents (Table 44). There were considerable variations in constituent levels in the leachates over the sampling dates. Except for zinc, concentrations of most constituents decreased in Phase II when compared to Phase I. The greatest decreases were noted for TOC and iron. These may have resulted from the dilution of the generated leachate volumes and may, in part, explain the lower concentration of contaminants found in the downstream groundwater during Phase II monitoring.

Chloride and sulfate concentrations were relatively low, a finding consistent with the low concentrations for these constituents found in the soil and sludge at this site.

Groundwater Analyses

During Phase I, four groundwater samples were taken from the shallow (OS-1 at 1.8 m) and deep (OS-2 at 5.6 m) wells. Samples were taken bimonthly from these two wells and also from the background well (BG at 7.9 m) and from the new, deep off-site well (OS-3 at 16.9 m) in the 12-mo Phase II monitoring. These samples were analyzed for selected chemical contaminants (or parameters). The results of Phases I and II are presented in Table 43 and Table 8 of Appendix E, respectively.

Background Groundwater--

The background sample in Phase I generally contained very low levels of contaminants (Table 43). The high lead content (0.08 ppm) in this sample could not be confirmed by subsequent analysis of the groundwater samples from the Phase II background well. The most noticeable deviation in contaminant levels in the background groundwater involved the substantial increase in sulfate in Phase II. This may be indicative of a high sulfate background level at this depth or disturbances during well drilling.

Except for sulfate, contaminant levels in the background groundwater ranged from low to nondetectable during Phase II monitoring and were generally less than the corresponding

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TABLE 44. CHEMICAL ANALYSIS OF LEACHATES FROM IN-REFUSE WELL (SITE 8)

	Phase I			
Constituent*	7/30/75	9/17/75	10/3/75	6/19/76
pH	6.2	7.2		
Tot. Solids	4965	19808		
TOC	3000	890	1160	2970
COD	8265	1194	5721	
TKN	254			
NH_4-N	198			
NO_3-N	0.28			
Cl	3			
SO_4	12			
Ca	617	43	47	
Cd	0.019	0.016	0.033	0.002
Cr	0.09	0.19	5.62	0.30
Cu	1.67	0.31	1.90	0.59
Fe	227	63	237	320
Hg	<0.0002			<0.0002
Ni				0.02
Pb	0.680	0.770	0.700	0.08
Zn				0.26

TABLE 44. (Continued)

Constituent*	Phase II†			
	11/11/76	3/30/77	5/18/77	9/18/77
Cd	0.050	<0.005	0.005	0.005
Cr	0.07	0.25	0.17	0.13
Cu	4.50	0.11	0.83	0.45
Fe	390	21	85	39
Hg		0.0006	0.0005	0.0010
Ni	1.10	0.03	0.31	0.10
Pb	2.0	0.07	0.32	0.21
Zn	17.0	0.59	4.60	2.40
Cl	11	<2	--#	11
SO_4	12	3	--#	14
TOC	17	21	1	71
Sp. Cond.	475	--#	10000	340

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*Specific conductance in μmhos/cm, all other constituents concentrations in ppm.

†No sample taken on 1/12/77 due to dry well.

#Insufficient sample.

concentrations in the three off-site wells (Figures 82 and 83 and Table 8 of Appendix E).

Downstream Groundwater--

Considerable variations were noted in contaminant levels in the groundwater over time and with sampling depths (Table 43). In Phase I, samples from the shallow off-site well (OS-1) showed higher levels of TKN, ammonium, calcium, chromium, iron, lead, and zinc when compared to the deep off-site well (OS-2). Conversely, the total solid levels in the OS-2 well were several times greater than those in the OS-1 well. Among the heavy metals in the shallow off-site groundwater, iron increased with subsequent samplings (from 0.70 to 27 ppm) and lead contents were as high as 1.15 ppm. These latter levels were consistent with the water-soluble lead concentration found in soils at the soil-groundwater interface. The data also suggests that lead had been leached, to some extent, to the groundwater existing at lower depths.

Since the TOC levels were high in samples from both the shallow and deep off-site wells, vertical migration of leachate in the form of organic substances was indicated. The overall data suggest that attenuation of contaminants by the soil at this site was relatively poor. The groundwater from off-site wells ranged from neutral to moderately alkaline (pH 7.0 to 8.2, depending on sampling date and depth). Although the soil was moderately acidic, the pH of the groundwater indicated that it was probably disturbed by well drilling. However, it gradually was shifted to the above pH range due to the buffering by the bicarbonates that are prevalent in most groundwater resources. These disturbances were also suggested by the relatively high TOC, COD, TKN, and calcium levels in the June 1975 sample in the shallow off-site well when compared to subsequent samples taken from the same well.

When the groundwater data from the OS-1 and OS-2 wells of Phase I were compared to that of Phase II, the large TOC concentrations in the two off-site wells and elevated concentrations in the OS-1 well of Phase I were not noted in Phase II. Meanwhile, exceedingly high concentrations of iron were detected at all three off-site wells during Phase II monitoring. During the same period, other metals - cadmium, chromium, copper, nickel, mercury, and lead - were also found at low to nondetectable levels in these downstream wells.

Lead, zinc, and chloride in the groundwater from the OS-2 (medium depth) well appeared to be higher than the corresponding concentrations from either the OS-1 (shallow) or OS-3 (deep) wells (Figures 82 and 83). These contaminants had apparently not been leached to the depth (16.9 m) where the OS-3 well was placed. TOC concentrations in the groundwater from the OS-3 well, however, were consistently high and an order of magnitude

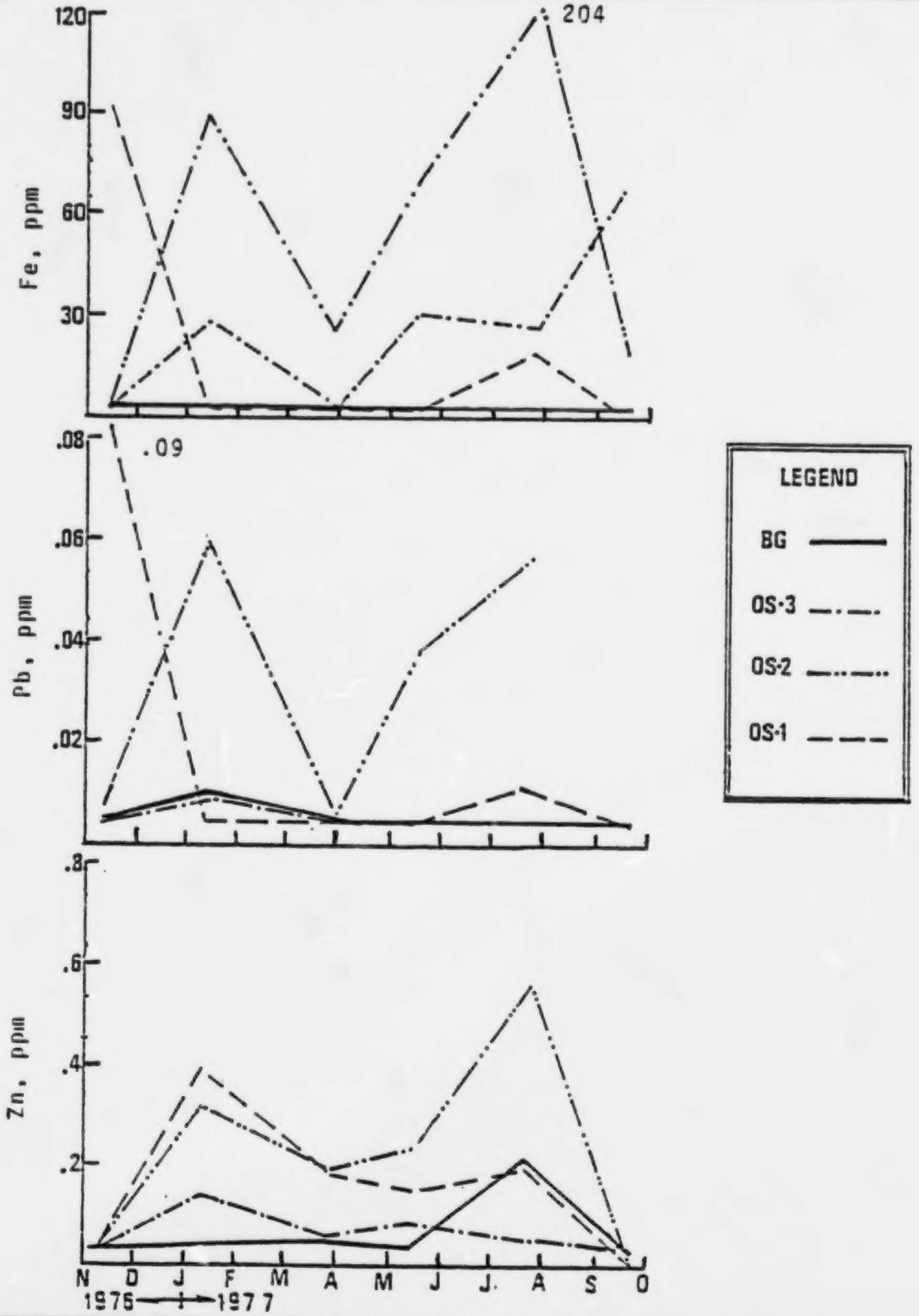

Figure 82. Fe, Pb, and Zn levels in groundwater. (Site 8)

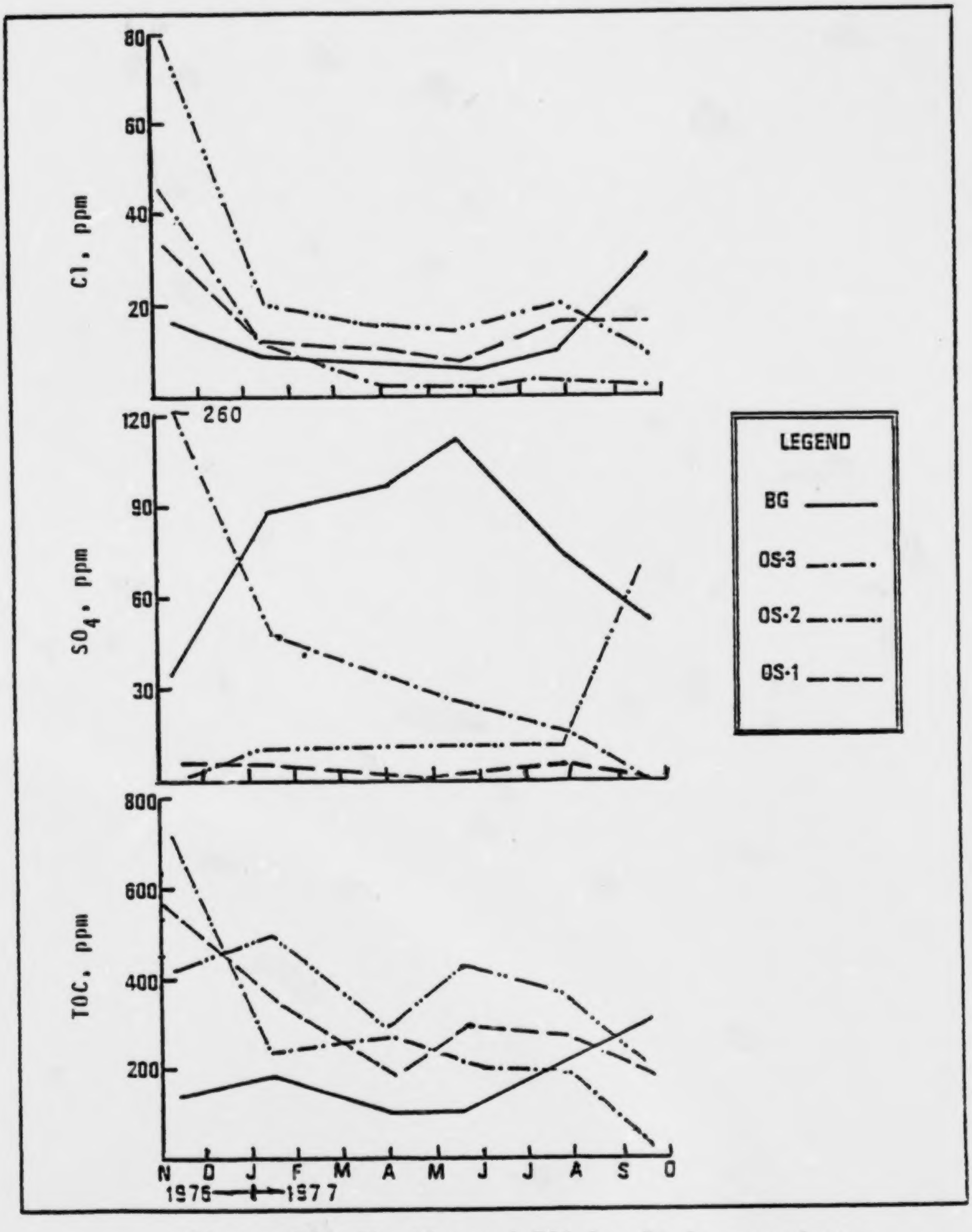

Figure 83. Cl, SO$_4$, and TOC levels in groundwater. (Site 8)

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greater than those in the shallower wells. If leachate from the landfill has migrated into the groundwater to considerable depths, more tests will be required to identify the organic species and possible contamination of the groundwater supply with fecal bacteria. Results of bacteriological analyses found no fecal coliform in all three wells, while fecal streptococcus was detected at only very small or insignificant concentrations (Table 45).

Environmental Impact Assessment

In determining the possible degradation of groundwater quality as a result of the landfilling operation at this site, concentrations of the selected contaminants were compared with the EPA drinking water standards (Table 46).

The background water showed concentrations of iron, lead, and TOC that exceeded the drinking water standards. Iron concentrations exceeded the standards five out of seven times. These concentrations (0.17 to 1.50 ppm) were not greatly elevated. In fact, the standard was only barely exceeded on most occasions.

Lead in the background groundwater exceeded the standard only one out of seven times. This occurred in the 1975 grab sample and was not confirmed by Phase II monitoring data. Also, lead was not detected in most of the Phase II samples.

The standard for TOC was exceeded two out of seven times, each one occurring in Phases I and II. Again, the high TOC (31 ppm) in the 1975 grab background sample did not appear in the Phase II samples. It was therefore unlikely that background groundwater was contaminated with organic pollutants.

The groundwater from downstream wells showed cadmium, copper, iron, lead, sulfate, and TOC exceeding the drinking water standards from 1 to 24 times.

Elevated levels of cadmium and copper were detected in downstream wells on one occasion each. Since these were from sample populations of 25 and 26 for cadmium and copper, respectively, gross contamination of the groundwater with these two metals appeared unlikely.

Iron levels exceeded the standard 24 out of 25 times in downstream groundwater. These levels increased considerably in the second phase of this study, with concentrations reaching as high as 204 ppm. Thus, it is evident that the downstream groundwater was heavily contaminated with iron as a result of the landfill operation.

Lead exceeded the standard eight out of 25 times. The high levels found in Phase I cannot be confirmed by the Phase II data.

TABLE 45. BACTERIOLOGIC EXAMINATION OF GROUNDWATER FROM OFF-SITE WELLS (SITE 8)

Date	Well	Fecal Coliform	Fecal Streptococcus
		colonies/100 mℓ	
7-28-77	OS-1	< 3	3
		< 3	4
		< 3	3
7-28-77	OS-3	< 3	23
		< 3	< 3
		< 3	21
9-18-77	OS-2	< 3	< 3
		< 3	< 3
		< 3	9

TABLE 46. NUMBER OF TIMES SAMPLED CONSTITUENT CONCENTRATIONS EXCEEDED EPA DRINKING WATER STANDARDS (SITE 8)

Constituent	Background Wells		Downstream Wells	
	Phase I	Phase II	Phase I	Phase II
Cd	0-1*	0-6	1-8	0-17
Cu	0-1	0-6	1-8	0-18
Fe	1-1	4-6	6-7	18-18
Hg	0-1	0-6	0-8	0-18
Pb	1-1	0-6	5-8	3-17
Zn	0-0	0-6	0-1	0-18
Cl	0-1	0-6	0-7	0-18
SO_4	0-1	0-6	0-7	1-18
TOC	1-1	1-6	8-8	16-18

* The first number indicates number of times standard was exceeded; the second number is sample population.

The lead levels in Phase II were generally very low or nondetectable, except for the three occasions on which the standard was exceeded (0.056, 0.064, and 0.090 ppm). Based on the lead concentrations and number of times the standard was exceeded, it is suspected that groundwater intercepted by the OS-1 and OS-2 wells was contaminated with lead.

Total organic carbon (TOC) was found at significant levels in downstream wells. The standard was exceeded 24 out of 26 times. Excessively large TOC levels were detected in the deep (OS-3) well, indicating passage of organic pollution into the deep groundwater. Bacterial tests indicated that, although fecal streptococcus was detected in some samples from the downstream wells, the levels were so low or nondetectable there appeared to be no concern for health hazard.

The sandy, moderately acidic soils, a shallow water table, and the disposal practice (sludge-only, lagooning, etc.) at this site has resulted in adverse effects on the groundwater supplies. Although the heavy metals showed limited migration through soils into the groundwater, contamination of iron and organic compounds (TOC) in the three off-site wells strongly suggested the poor quality of the downstream groundwater. The data also suggest continual monitoring and detailed examinations of organic species and fecal bacteria in the groundwater.

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APPENDIX A

GAS PROBE AND MONITORING WELL PLACEMENT PROCEDURES

IN-REFUSE WELL

The monitoring well in the landfills was drilled to the groundwater table. A core auger or bucket rig was used for drilling holes in refuse. An air rotary drill may be used but is subject to fouling in refuse. Figure 1 shows a typical installation.

Experience indicated that for our typical 4-in diameter monitoring well, the optimum well bore diameter was a minimum of 6 in, and preferably 8 in or greater. During the drilling, refuse was pulled loose and protruded into the hole. This led to difficulties during the placement of the gas probes attached to the outside of the well casing and in backfilling.

Soil boring logs of the material brought to the surface during the well drilling operation were carefully recorded.

After the location of the well was determined on the site and before the well driller arrived, a core sample of the cover soil material was taken for determination of permeability. The Field Sampling Instruction Manual gives detailed instructions on obtaining the sample.

Two refuse samples were taken for determination of moisture content from each hole at the one-third and two-thirds overall landfill depth, respectively. Approximately one shovelful of refuse and/or sludge material was placed in a plastic bag and sealed. The bag containing the sample was placed in a second plastic bag and again sealed. This double bagging was to minimize moisture loss.

Upon reaching the bottom of the landfill (when the auger brings up mostly soil), a soil or core sample (approximately a shovelful) was taken and placed in a sterile plastic specimen bag. Two additional samples were taken following the same procedure, one halfway between the landfill bottom and the groundwater, and the other at groundwater level.

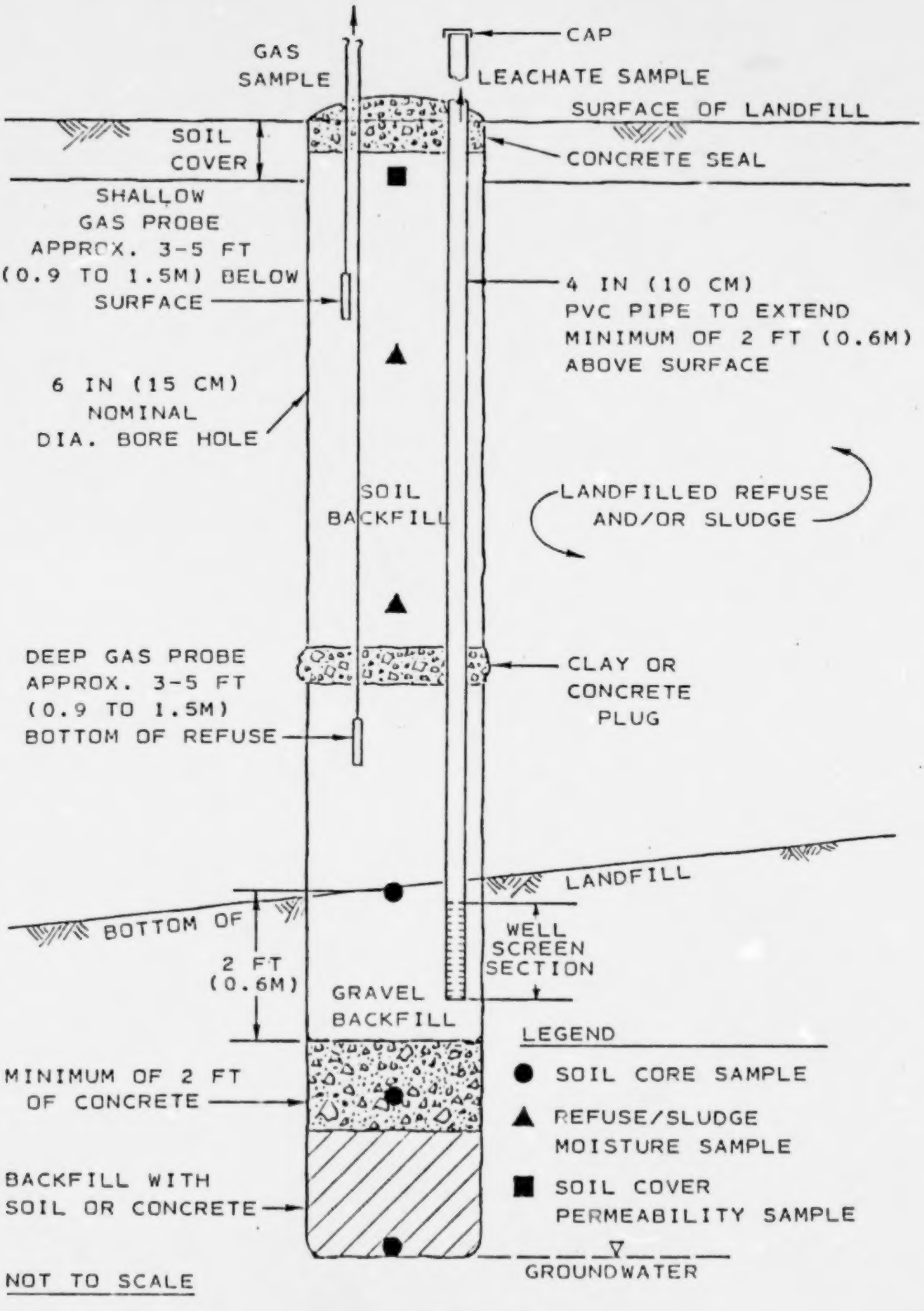
GAS SAMPLE
CAP
LEACHATE SAMPLE
SURFACE OF LANDFILL
SOIL COVER
CONCRETE SEAL
SHALLOW GAS PROBE APPROX. 3-5 FT (0.9 TO 1.5M) BELOW SURFACE
4 IN (10 CM) PVC PIPE TO EXTEND MINIMUM OF 2 FT (0.6M) ABOVE SURFACE
6 IN (15 CM) NOMINAL DIA. BORE HOLE
SOIL BACKFILL
LANDFILLED REFUSE AND/OR SLUDGE
DEEP GAS PROBE APPROX. 3-5 FT (0.9 TO 1.5M) BOTTOM OF REFUSE
CLAY OR CONCRETE PLUG
BOTTOM OF LANDFILL
2 FT (0.6M)
WELL SCREEN SECTION
GRAVEL BACKFILL
LEGEND
● SOIL CORE SAMPLE
▲ REFUSE/SLUDGE MOISTURE SAMPLE
■ SOIL COVER PERMEABILITY SAMPLE
MINIMUM OF 2 FT OF CONCRETE
BACKFILL WITH SOIL OR CONCRETE
GROUNDWATER
NOT TO SCALE

Figure 1. Typical in-refuse well details.

Since the exact distance to groundwater was not always known, several samples around the presumed mid-depth were obtained and retained until the midpoint location was established.

Two gas probes were placed in the in-refuse well, one at approximately 3 to 5 ft below the surface and the other 3 to 5 ft above the landfill bottom. These gas probes were located outside of the well casing.

The materials used and placement depths in backfilling of the in-refuse well are shown in Figure 1. In brief, the well was first backfilled with concrete, and the well casing and deep gas probe inserted. The well was again backfilled with gravel, then with concrete, and finally native material. A concrete cap was placed at the top to secure the well.

PLUME AND GROUNDWATER WELLS

Two wells were placed in the presumed groundwater down gradient direction from the in-refuse well described above. These wells did not penetrate any refuse, and were approximately 30 m (100 ft) from the in-refuse well.

One well penetrated the groundwater table elevation to a depth of 0.61 m (2 ft). This well was termed the shallow well. The second well penetrated the groundwater table elevation to a depth of about 6.09 m (20 ft) (site conditions permitting). This well was termed the deep well. Figure 2 illustrates typical construction details for each well.

At Sites 1 and 3, six wells were placed in two parallel lines normal to the direction of groundwater flow. The lines were 45 to 75 m (150 to 250 ft) apart and the wells in each line were spaced 75 to 90 m (250 to 300 ft) apart on centers. Each contained four sampling levels separated by bentonite clay plugs. Sand and gravel were backfilled in between the clay plugs. Figure 3 illustrates typical construction details for each well. All of the sampling points for each well penetrated the groundwater table and were generally placed about 3 m (10 ft) apart.

Background groundwater wells utilizing the same well construction as in Figure 3 were placed several hundred feet above the disposal area at Sites 1 and 3. At other sites, a background well was constructed at one depth using the same well construction as shown in Figure 2.

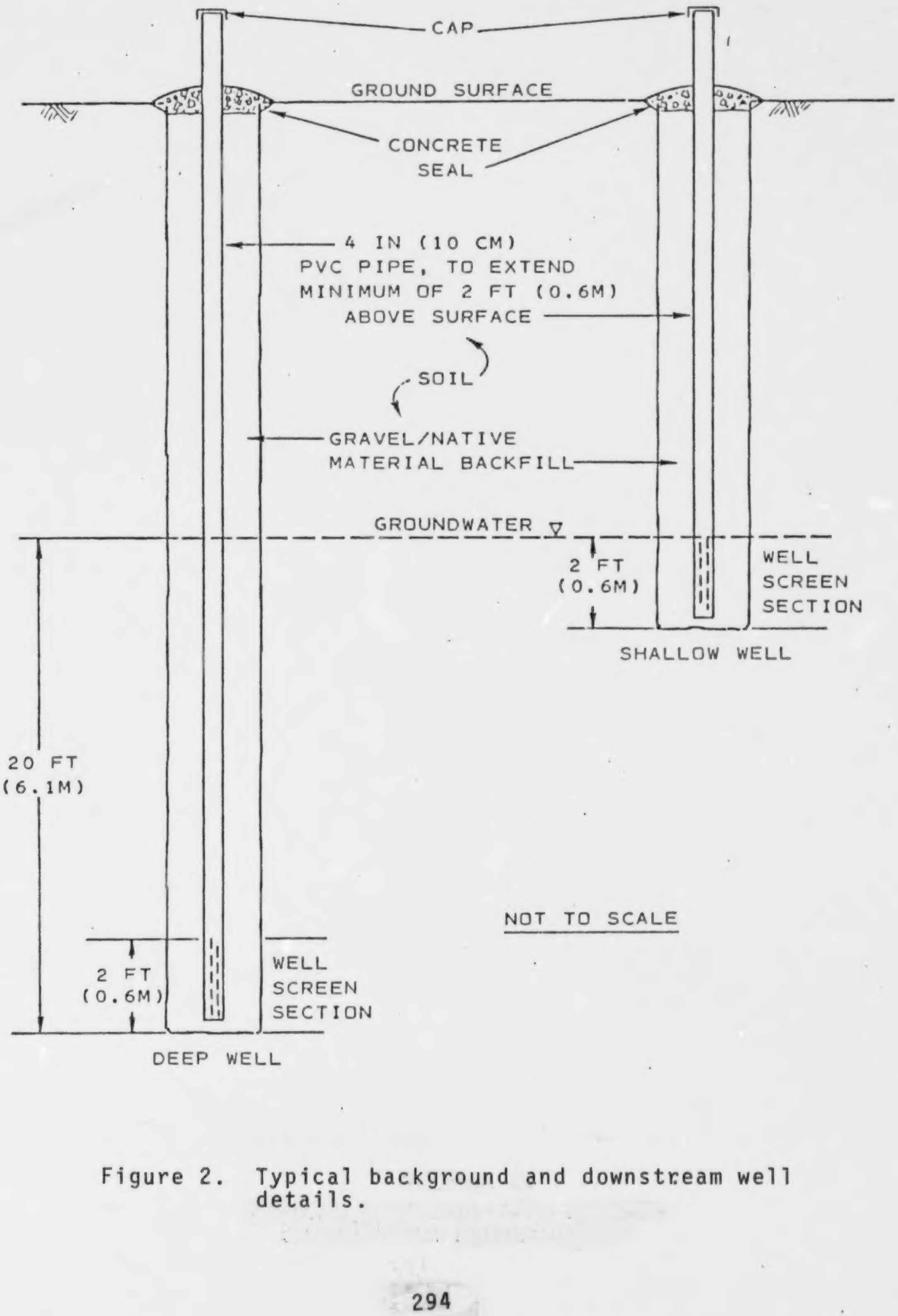
CAP
GROUND SURFACE
CONCRETE SEAL
4 IN (10 CM) PVC PIPE, TO EXTEND MINIMUM OF 2 FT (0.6M) ABOVE SURFACE
SOIL
GRAVEL/NATIVE MATERIAL BACKFILL
GROUNDWATER
2 FT (0.6M)
WELL SCREEN SECTION
SHALLOW WELL
20 FT (6.1M)
NOT TO SCALE
2 FT (0.6M)
WELL SCREEN SECTION
DEEP WELL

Figure 2. Typical background and downstream well details.

311

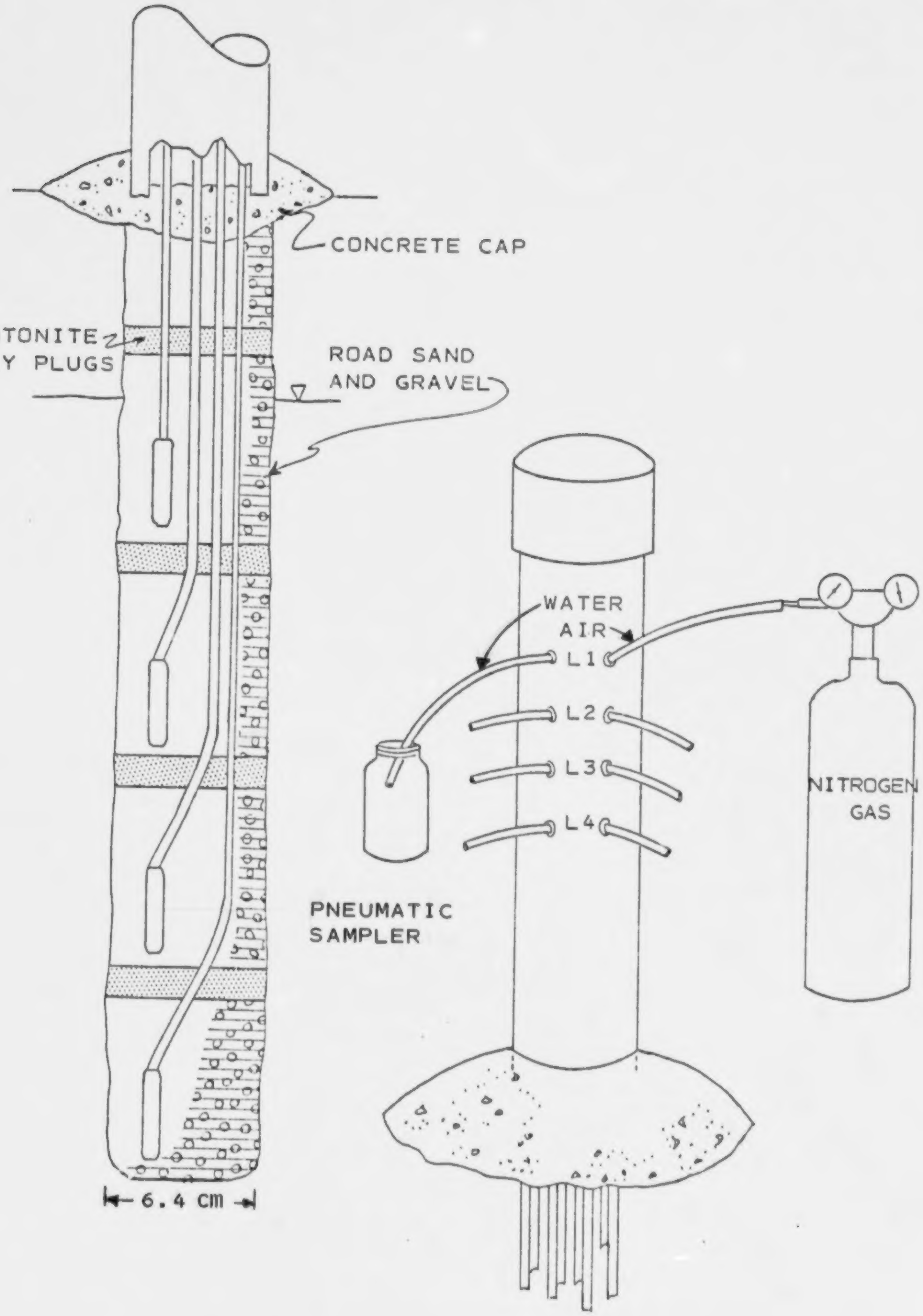
CONCRETE CAP
BENTONITE CLAY PLUGS
ROAD SAND AND GRAVEL
6.4 cm
WATER
AIR
L1
L2
L3
L4
NITROGEN GAS
PNEUMATIC SAMPLER

Figure 3. Typical off-site plume well details showing four pneumatic samplers and close-up of sample collector.

APPENDIX B. GROUNDWATER READINGS FROM MONITORING WELLS

Well	Top of Pipe Elevation (m)	Groundwater Elevation (m) *					
Site 1		10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
IR	571.92	563.08	563.14	563.06	563.11	563.06	563.54
OS-X	564.29	560.02	560.33	560.33	—	—	—
EX-1	578.18	559.33	559.82	559.87	559.84	559.57	558.63
EX-2	573.04	559.55	559.98	559.88	559.98	559.42	559.68
EX-3	570.88	561.03	—	—			
Site 2		11/1/76	1/21/77	3/9/77	5/18/77	7/18/77	9/13/77
IR	351.95	344.63	344.58	344.63	344.46	344.58	345.12
OS-1	345.87	342.37	342.44	342.55	342.73	—	343.41
OS-2	346.18	341.81	341.94	342.14	342.62	342.37	343.49
BG	347.54	343.47	343.42	343.12	343.55	343.52	344.24
EX-1	351.78	338.07	338.04	338.07	337.99	338.07	—
EX-2	349.74	338.14	338.11	338.11	338.11	338.01	—
Site 3		11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
IR	311.97	306.38	306.60	306.36	307.99	308.19	306.73
OS-X	308.46	303.07	300.99	303.05	303.33	303.20	303.99
EX-1	309.76	303.64	303.51	303.51	304.73	303.39	304.39
EX-2	308.64	303.81	303.74	303.68	304.22	303.89	305.57
EX-3	308.44	303.49	—	—	303.87	303.01	—
EX-4	311.39	304.07	303.92	303.79	304.53	304.91	304.95
EX-5	308.09	303.46	303.46	303.40	303.36	303.51	304.37

APPENDIX B. (continued)

Well	Top of Pipe Elevation (m)	Groundwater Elevation (m) *					
Site 4		11/24/76	1/19/77	3/6/77	5/21/77	7/21/77	9/16/77
IR	423.04	420.68	420.83	421.35	421.23	421.13	420.52
OS-X	422.02	419.05	419.14	419.36	419.20	419.18	419.03
BG	430.14	424.55	424.19	425.13	424.73	424.73	424.40
EX-1	423.84	420.36	419.31	419.98	419.98	419.98	419.67
EX-2	423.77	420.47	420.60	421.28	421.11	420.93	420.06
Site 5		11/15/76	1/19/77	4/1/77	5/9/77	8/1/77	9/21/77
OS-1	16.46	14.00	14.36	14.36	14.26	14.26	14.28
BG	70.83	57.11	57.24	56.98	56.93	57.03	56.55
Site 6		11/10/76	1/10/77	3/30/77	5/17/77	7/26/77	9/16/77
OS-1	19.95	17.66	—	17.41	17.22	16.95	18.32
OS-2	19.94	14.74	14.85	14.81	14.81	14.58	14.71
OS-3	20.93	—	—	—	—	—	—
BG	27.15	17.82	17.52	17.41	17.42	17.39	17.55
Site 7		11/12/76	1/11/77	3/31/77	5/18/77	7/26/77	9/19/77
OS-1	265.48	259.78	259.44	259.92	260.25	259.81	259.41
OS-2	265.48	259.71	259.33	259.80	260.17	259.79	259.49
BG	283.46	265.61	265.25	265.67	266.19	256.81	265.35
Site 8		11/11/76	1/12/77	3/30/77	5/18/77	7/27/77	9/18/77
OS-1	198.12	197.51	197.13	195.45	195.79	196.82	197.11
OS-2	198.12	197.52	196.94	197.88	197.11	195.78	197.18
OS-3	197.82	193.62	189.44	189.90	190.32	190.00	189.96
EX-1	207.57	206.27	206.01	206.74	206.33	205.61	206.12
BG	213.36	211.59	211.01	212.29	211.18	210.87	210.92

* Elevations above mean sea level.

APPENDIX C

FIELD SAMPLING INSTRUCTION MANUAL

The objective of field sampling is to obtain representative leachate, groundwater, gas, sludge, and mixed refuse-sludge samples from each of the case study sites. The accuracy and care taken during sampling cannot be overemphasized. An accurate analysis is directly dependent upon the care taken by field personnel in drawing and shipping the requisite samples.

This manual is intended to provide field personnel with a guide to the precise procedures to be employed as well as alternative procedures, where applicable, for coping with unanticipated problems.

SAMPLING CODE CONVENTION

In labeling, the following information should appear on each sample container (Figures 1 and 2).

- Date: Month and day only, use number for months.
- Sample sequence number: Each sample will be given a sequence number starting with 1 for the first sample. Consecutive numbers will be assigned for additional samples taken from each site. For example, the second leachate sample taken will be assigned the number "2."
- Project code: This five-digit code uniquely identifies this specific project, i.e., SCS-34.
- Location code: Sample site location codes are taken from the commercial airport nearest to the case study site i.e., FYV.
- Sample hole designation (for groundwater sampling): well designation (A, B, or 1-6), and sample depth designation (1-4).
- Gas probe depth:
  A = shallow probe
  B = deep probe.

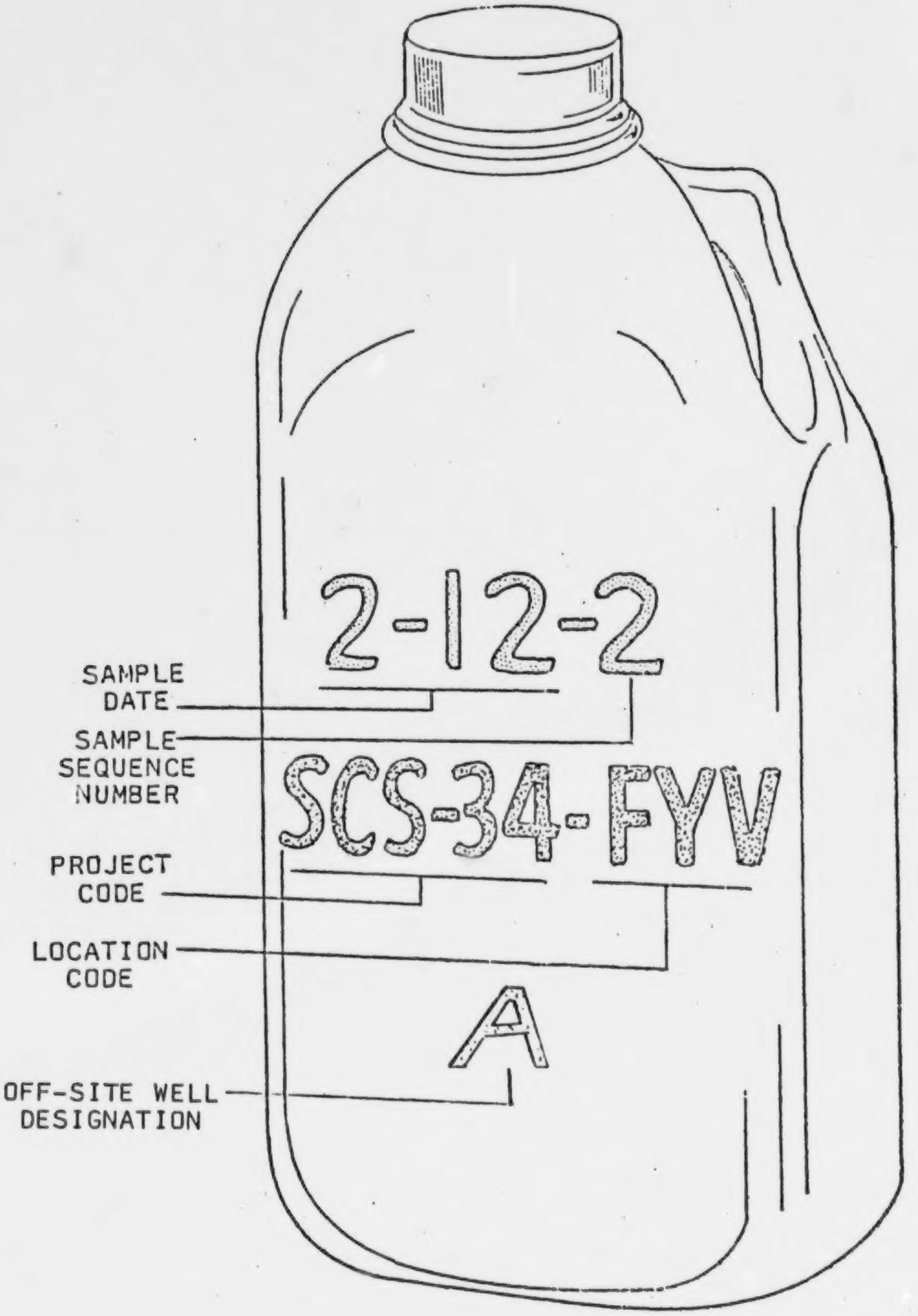
2-12-2
SAMPLE DATE
SAMPLE SEQUENCE NUMBER
SCS-34-FYV
PROJECT CODE
LOCATION CODE
A
OFF-SITE WELL DESIGNATION

Figure 1. Leachate sampling container labeling.

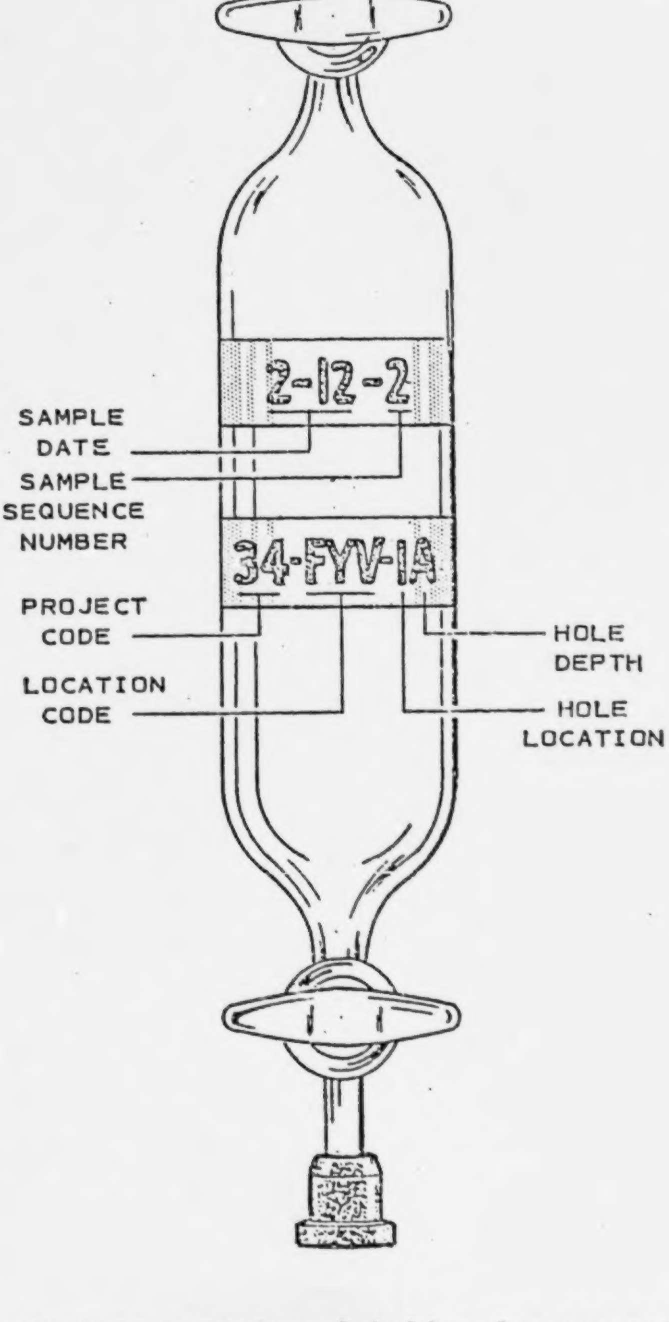
2-12-2
SAMPLE DATE
SAMPLE SEQUENCE NUMBER
34-FYV-1A
PROJECT CODE
LOCATION CODE
HOLE DEPTH
HOLE LOCATION

Figure 2. Sampling container labeling for gas sample bottles.

For leachate and groundwater samples, both sides of the sample bottles should be labeled with a waterproof marking pen. Mark each container in LARGE NEAT BLOCK LETTERS as in Figure 1. Use dashes (not slashes) to separate items. On groundwater sample containers for offsite wells, be sure to designate which well is being sampled.

For gas samples, two strips of masking tape should be placed on the containers as shown in Figure 2. Label the tape as per the above-mentioned procedure. Do not use waterproof pens directly on glass because the markings are almost impossible to remove.

LEACHATE AND GROUNDWATER SAMPLING PROCEDURES

Nonpneumatic Well Sampling

A leachate sample will be obtained from the in-refuse well. Groundwater samples will be taken from the background and shallow and deep off-site wells. The materials required are:

- One copy Field Sampling Instruction Manual
- Styrofoam-lined corrugated shipping cartons
- Adequate supply of 1- and 2-l plastic bottles*
- Sampling unit with two sample bottles (Figure 3)
- One thermometer with a range of 0 to 150°C
- Corning Model 3 pH meter (portable)
- One plastic funnel
- Black waterproof marking pens
- Four packs minimum of "blue ice" for shipping (the "blue ice" should be frozen prior to obtaining the leachate samples; use motel ice machine or restaurant freezer)
- Several rolls of fiber packing tape or duck tape
- Notebook for field notes

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*These containers are prepared for field use as follows: the polyethylene containers are first washed with hot tap water and cooled and rinsed with AA grade 1:1 nitric and hydrochloric acid; cold tap water is used to flush the acid remains from the bottles; and, finally, each bottle is rinsed several times with double-distilled deionized water. Caps are treated in a similar fashion. The bottles are then capped tightly and prepared for shipment to the field.

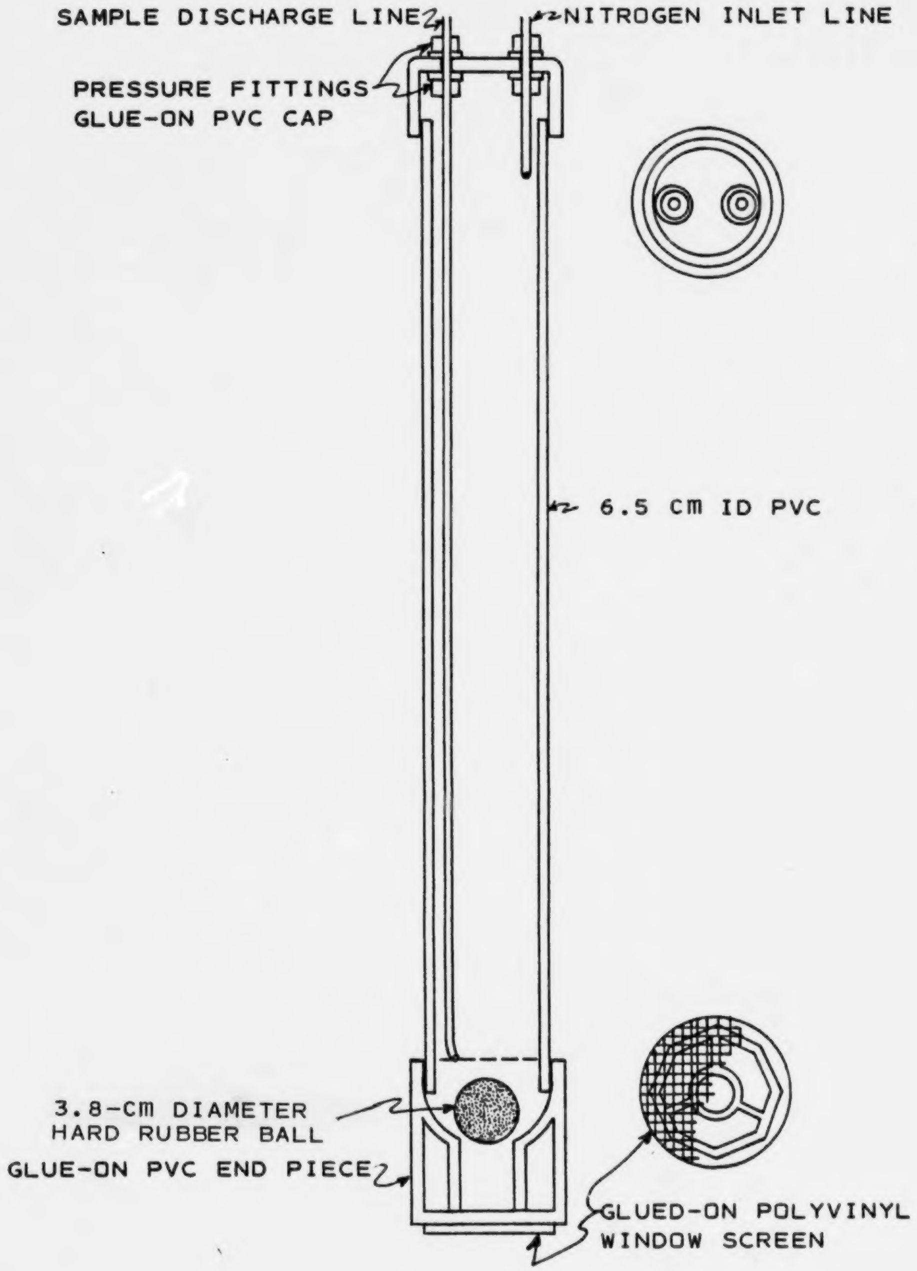
SAMPLE DISCHARGE LINE
NITROGEN INLET LINE
PRESSURE FITTINGS
GLUE-ON PVC CAP
6.5 cm ID PVC
3.8-cm DIAMETER
HARD RUBBER BALL
GLUE-ON PVC END PIECE
GLUED-ON POLYVINYL
WINDOW SCREEN

Figure 3. Pneumatic ejection groundwater sampler design.

- Master list of sample sequence numbers and sampling dates by site

- One styrofoam ice chest.

Prior to taking a sample, the well should be flushed several times. A premarked plastic sample bottle is placed inside the device and the weighted section attached. The entire sampling device is then lowered into the well (Figure 3). The sample device is pulled up after the flow of air bubbles subsides. The sample bottle is removed and securely capped.

In Phase I, only one 2-l sample was taken from each well. The samples were not acidified prior to shipment. In Phase II, two 1-l samples were obtained; in the field one sample was treated with concentrated hydrochloric acid to pH <2 and the other was untreated. Upon completion of sampling at a site, check:

- Sample Record Form to see that all samples and measurements have been taken

- That all sample bottles have been properly marked and accounted for

- That all observations, remarks or comments have been duly recorded on the reverse side of the Sample Record Form.

Pneumatic Well Sampling

Groundwater samples will be obtained from each of the four levels of the pneumatic wells. The materials required are:

- Sample bottles

- Gas regulator

- Compressor-vacuum pump

- Greater than 2.5-cm (1-in) crescent wrench to fasten 2-stage regulator to gas cylinder and crack open pipe caps

- Shipping cartons for samples

- Individual site Sample Record Forms to record depth measurements, checking off samples taken, and recording comments: a map of the site showing general site layout and locations of all wells is attached

- 30.5-m (100-ft) milar coated Stanley measuring tape with several heavy washers attached to the end ring

- Clipboard

- Acetone-base black marking pen
- Glass fiber tape
- Pocket knife
- One pair disposable rubber gloves
- Plastic bags (1- or 2-gal size)
- Shipping labels
- Special weighted PVC sampling tube
- Nitrogen gas cylinder.

As a general rule, the size of a gas cylinder has been estimated based on presumed needs and a size specified which should be slightly in excess of that required for a complete round of sampling while still being portable in the field. A "Q" size gas cylinder is to be picked up at the beginning of a sampling round and then returned to the supplier upon finishing that round of sampling.

Field Sampling--

Sites using pneumatic ejection-type samplers all have column posts with premarked tubing emerging from the column post side wall. Construction has been standardized such that the air and water lines for each sampling device are arranged in descending order of depth as indicated in Figure 4. Tubing for the uppermost probe, level 1, is at the top and the deepest, level 4, at the bottom of the column post. The air tubes by arbitrary convention are located on the right side and sample discharge tubes on the left.

In case of damage to the exposed post and tubing, reconstruction of the unit and identification of tubes is possible by carefully removing damaged pieces and observing the location of tubes coming through a plastic plate set into the base of the concrete slab. This plastic plate has four holes through which a specific set of air and discharge tubes have been pulled through.

The base plate is numbered from 1 to 4 to identify groundwater levels. Extra tubing where available was placed in a simple coil in the inside of the column post. This can be pulled up and out in case of external damage to exposed tubing. Other sites have merely used marked air and water lines taped together. Markings are down near ground level inside the column posts.

The gas regulator should be carefully threaded onto the nitrogen gas cylinder by hand to start the threading correctly.

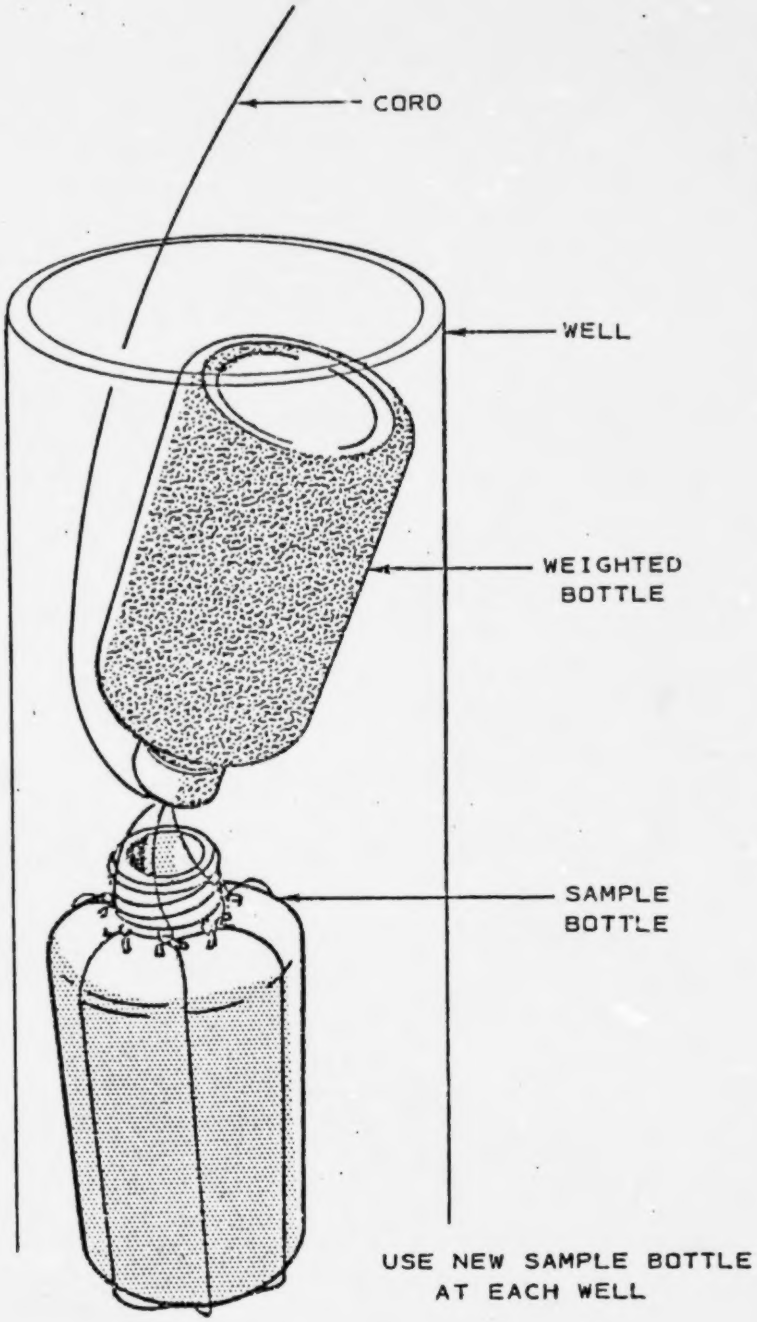
CORD
WELL
WEIGHTED BOTTLE
SAMPLE BOTTLE
USE NEW SAMPLE BOTTLE AT EACH WELL

Figure 4. Sampling unit for liquid samples.

After having threaded on the gas regulator as much as possible by hand, tighten with the wrench. To open the gas cylinder, first:

- Check to see that black needle valve is closed
- Open main gas cylinder valve
- Adjust pressure regulator valve to working pressure of 50 psig.

For those sites which do not have very deep wells, the pressure regulator can be set to a lower pressure setting. This can be estimated on the basis of approximately 0.7 cm (2.3 ft) of water lift per unit psig. The tubing has a maximum design pressure of approximately 60 psig. Exercise caution when using greater pressures since excessive pressure may damage the sampling device and render it useless for further sampling. The best gauge of correct pressure setting is to base it on the rate at which sample is discharged into sample bottle. Subsequent field procedure to be used is:

- Connect the gas cylinder to the influent air hose.
- Crack the needle valve on the gas regulator to allow air to pressurize the sample probe.
- Adjust pressure regulator discharge pressure.
- Flush well several times.
- Place discharge hose line into sample-collection container. After a full sample bottle has been collected, quickly change bottles. Two 1-l sample bottles will be taken of each sample. One 1-l sample bottle is acidified with concentrated hydrochloric acid to pH <2, and the other bottle unacidified.
- Completely empty contents of each sample probe.
- Preferably before or immediately after filling, label each bottle using black marking pen with the appropriate identification described (with illustrations) on the particular site. Sample Record Form: write out the sample identification exactly as indicated on the Sample Record Form. Do not use your own nomenclature.
- Repeat the procedure for remaining sample probes.

The following is presented as a troubleshooter's guide when it is not possible to get a liquid sample using the conventional procedure. The following conditions or symptoms may occur,in which case the following methods of rectifying or solving the problem should be employed:

a. Symptom: Blows only air through water discharge line.

Cause No. 1: Bottom inlet plugged

Procedure: Connect air hose line to vacuum connection on compressor-vacuum 12-V pump. Tightly clamp off water hose line. Draw vacuum for 10 to 15 min. Repeat conventional procedure. If some water blows up the line, seal at bottom where inlet has broken. Repeat procedure until full flow occurs.

If no change, pour water down the air line to fill probe, pump out and repeat procedure.

Cause No. 2: Groundwater level below probe inlet

Procedure: Nothing can be done.

b. Symptom: Blows air after small quantity of water has been air-lifted to surface.

Cause No. 1: Air-water house lines are mixed.

Procedure: Change gas cylinder or compressor pump to the water hose line.

If an approximately 1-gal quantity of water is subsequently pumped to the surface, fairly valid confirmation that the air and water hose lines have been inadvertently mixed. (However, all such probabilities should have been corrected by this time.) If it still blows air with no change, see 1.

Cause No. 2: Groundwater level just up to or slightly into probe

Procedure: Repeat pumping steps until complete sample obtained.

Cause No. 3: Inlet partially blocked or very slow percolation into probe

Procedure: See step 1.

c.	Symptom:	No water or air ejected from water line
	Cause:	Either the probe is silted-in or the water hose line is plugged
	Procedure:	Blow air down water hose line to suspend silt in available water solution. Quickly change to conventional procedure. If partially successful, repeat to completely evacuate silt load from probe until discharge runs clear. If still no flow, add water to probe and pump out. Repeat procedure.

BACTERIOLOGICAL SAMPLING PROCEDURE

Sampling of water for bacteriological examination requires that the sampling equipment and containers be disinfected prior to collecting water. The materials required are:

- Sterile sample bottles (supplied by laboratory) - sufficient quantity for 3 samples/well
- Disinfectant - pool chlorine, Clorox, or equivalent
- EPA Manual on Waterwell Construction (includes disinfection procedures)
- 3-5 empty 5-gal containers or equivalent
- Swimming pool chlorine check kit
- Gasoline pump w/<2 in I.D. hose
- Large plastic bags to encase pump and hose after disinfection
- Shipping boxes, styrofoam liners, labels
- Blue ice
- Disposable gloves
- Disposable paper cups for obtaining water samples for chlorine testing
- Whirl-pak or small new plastic bags for placing sterilized bottle cap inside while sampling.

Field Sampling

The following procedures should be taken step-by-step:

- Obtain normal samples.
- Disinfect well:
  - Calculate and prepare in large containers sufficient quantity (approximately 2x volume) of disinfectant solution, taking into consideration concentration of available disinfecting agent. Desired final concentration to be 100 ppm or greater.
  - Pour some excess down internal sides of well casing to disinfect inside casing walls. Make sure all internal surfaces of casing have been wetted.
  - Add inlet hose to container and shove outlet hose as far below water surface as possible.
  - Pump disinfectant into well.
  - Repeat for remaining containers, taking special caution not to let hose touch anything while transferring from one container to another. If possible, recirculate water in well, allowing disinfecting solution to run down external area of hose in well.

  Note: Hose and pump are now disinfected. Carefully place hose (inlet and outlet) into large plastic bags while wearing disposable gloves. These will be used the following day to remove water from well and must not become recontaminated.

- Let disinfectant stand for 24 hr.
- Set up pump and hose, taking care to use gloves; do not allow either inlet or outlet hose to come in contact with soil, equipment, etc. Do not use pump for any other purpose in the meantime because it was disinfected 24 hr previously.
- Start motor and pump well to obtain sample of water.
- Test sample for chlorine residual (use swimming pool kit). If residual is noted, continue pumping until no residual is detected after two consecutive chlorine tests.
- Restart pump and collect three samples from each well with previously sterilized bottles. Be very careful when removing cap that fingers touch neither the inside

of the cap nor the bottle. Place cottle under stream of water and fill about 7/8 full. Screw on cap tightly. If sample is to be used for withdrawing samples, make sure it has been disinfected by soaking in chlorine solution (100 ppm) overnight. Take necessary precautions to see that sample does not become contaminated by using new plastic gloves for handling. Store samples, rope, etc., in new plastic bag.

- Chill samples in ice water until shipment time.
- Pack bottles securely with sufficient blue ice to maintain temperature at approximately 4°C and ship air freight to laboratory.
- Record and report any difficulties in sampling while still in field. It will do no good to anlyze these samples unless all are maintained in a sterile condition.

GAS PROBE SAMPLING PROCEDURE

Gas samples will be obtained from probes placed in the in-refuse well hole. Each probe is situated at a different depth within the hole. The materials required are:

- 1/4 in I.D. rubber hose (surgical tubing is adequate), 2 to 6 in lengths
- Sample bottle(s) - 250 ml (Corning No. 9500)*
- Masking tape
- Rubber suction bulb, aspirator type
- One copy SCS Field Sampling Instructions
- Styrofoam-lined corrugated shipping cartons
- Several rolls of fiber-packing tape or duck tape
- Notebook for field notes

*Gas burettes are to be immersed in a solution of detergent and water to remove residue soils or other foreign material. Insolubles will be removed by immersing burette in acetone. Residues that might have remained will be removed by soaking burettes in aqua regia. The burettes are then rinsed in distilled H_2O and dried in the oven at 103°C for 30 minutes. The burettes are removed and placed in the desiccators for 30 minutes. Upon cooling, the stopcocks are greased with Apiezon N grease to insure a tight seal. The burettes are then evacuated with a vacuum pump just prior to shipment to the field.

- Master list of sample sequence numbers and sampling dates by site.

Gas Sampling

Refer to Figure 5 while reading instructions. The procedure is as follows:

- Mark sample bottles as shown in Figure 2.
- Remove rubber stopper from the exposed end of one gas probe.
- Slip the end of one of the 6 in pieces of rubber hose over the probe end.
- Slip the other end of the same rubber hose over one end of the sample bottle
- Slip one end of the second piece of rubber hose over the other end of the sample bottle.
- Slip the other end of the rubber hose onto the rubber bulb.
- Open the sample bottle stopcock nearest the gas probe. Note: The sample bottle has been evacuated to remove any contaminants from the bottle. Thus, when the stopcock is opened, a brief hissing noise will be heard. This is the sound of the vacuum being filled. If the hissing sound is not heard, one of the stopcocks may have been opened during transport or at some other time prior to sample taking. Make a note of this fact and continue the prescribed sampling procedure.
- Open the second stopcock.
- Begin aspirating the rubber bulb to draw in gases within the probe's area of influence. The number of squeezes necessary varies with the probe depth. A rule of thumb: one squeeze is required for each two ft of probe depth.
- When the appropriate number of squeezes have been taken, close the stopcock nearest the rubber bulb.
- Close the other stopcock.

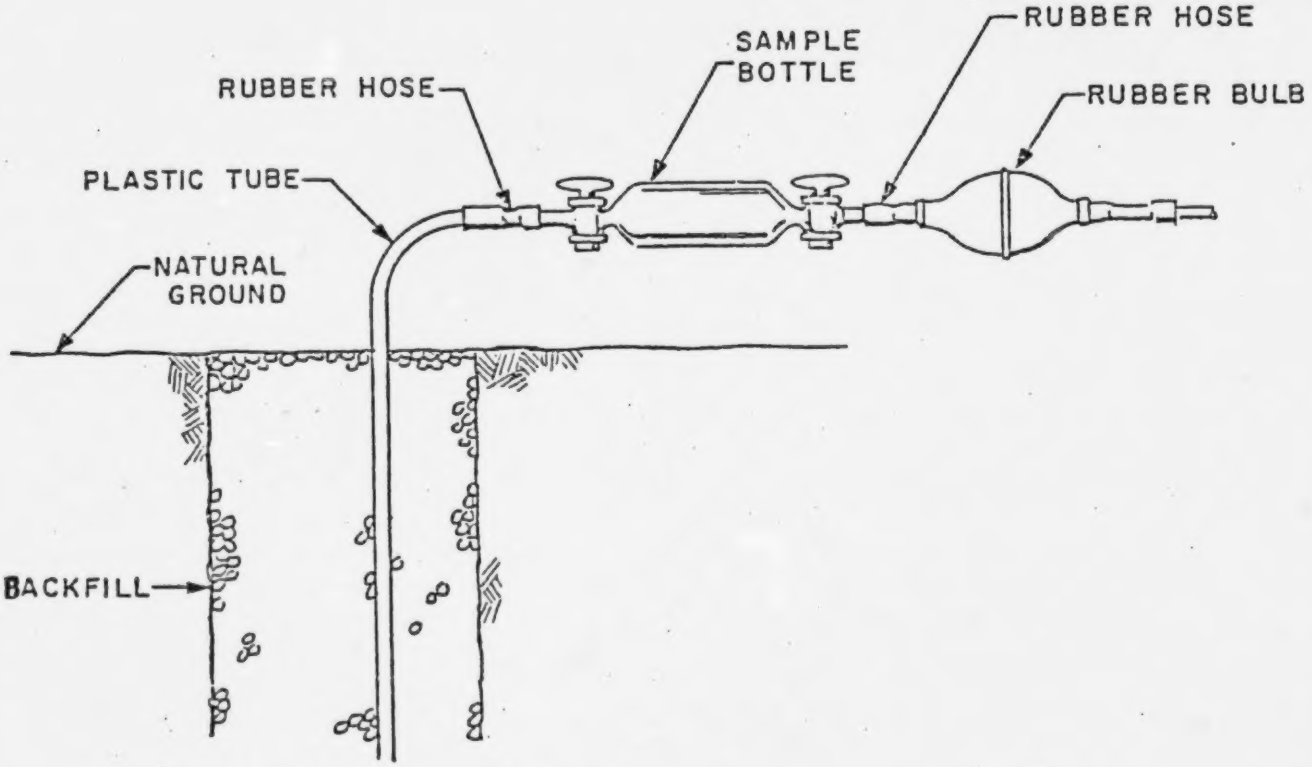
SAMPLE BOTTLE
RUBBER HOSE
RUBBER HOSE
RUBBER BULB
PLASTIC TUBE
NATURAL GROUND
BACKFILL

Figure 5. Gas sampling schematic.

- Remove the sampling apparatus from the gas probe and replace the rubber stopper (cap) on the gas probe end.

- Follow steps numbers 1-11 until a sample is obtained from each of the gas probes.

SOIL AND REFUSE SAMPLING PROCEDURE

Soil and refuse samples will be obtained from well locations during drilling and placement of the in-refuse well. The materials required are:

- One copy Field Sampling Instruction Manual
- Styrofoam-lined corrugated shipping cartons
- Adequate supply of commercially available polyethylene bags
- Several black waterproof marking pens
- Sufficient "blue ice" for shipping
- Several roles of fiber-packing or duck tape
- Notebook
- Master list of sample sequence numbers and sampling dates by site
- One 4 lb hammer
- One shovel
- Core sampling device
- One tarp 8 ft x 8 ft.

Soil Permeability Sampling

Locate an area of the site where soil cover has been placed over refuse for some time. With a shovel excavate the first inch or so of soil to remove grass, weeds, and organic material until the soil appears uniform in texture. Drive the sample device (with hammer) to a depth of about 12 in. Carefully excavate around the sampler and remove it, seal both ends and place in a double plastic bag. Seal bag and label with site designation.

Refuse Sampling from In-Refuse

Refuse samples will be taken from the bore hole at approximately one-third and two-thirds depths of the landfill, respectively.

Place approximately one shovelful of refuse and/or sludge material in a double plastic bag, seal and label properly.

Soil Sampling from In-Refuse Well

Three soil core samples will be taken from each site. The first sample will be obtained from the bottom of the bore hole at the refuse/soil interface. The second and third samples will be taken half the distance to groundwater and at the soil/groundwater interface, respectively. A split-tube or Shelby tube sampler will be used depending on local well driller equipment capabilities. Place about 1/3 lb of soil sample in a double plastic bag, sealed and labeled properly.

After the core samples are taken, the sides and ends will be sliced off and the center portion secured and placed in a double plastic bag, sealed and labeled properly.

PRESERVATION AND SHIPMENT OF FIELD SAMPLES

Liquid, soil, and refuse or sludge samples will be preserved by chilling in an ice chest packed with blue ice. Preparatory to placing sample bottles into the chest or shipping carton, check to insure that all sample bottles are properly labeled and that caps are tightened down. Carefully pack the bottles upright in the shipping container. Mark in large block print THIS SIDE UP on all four sides.

It is particularly important that the gas sample bottles must be wrapped with multilayers of paper or in packing sleeves to prevent breakage and shipped in styrofoam-lined corrugated containers. It is preferable that the samples be sent to the laboratory by air freight. The collective samples for each site will be insured for $1,000.

APPENDIX D

METHODS FOR SAMPLE PREPARATION AND ANALYSIS

The following procedures were standardized for the preparation and analysis of sewage sludge, soil, leachate, and groundwater samples received from the case study sites.

SAMPLE PREPARATION

Soils and Sludges

A sequential extraction, first with deionized water and then with concentrated nitric acid, was used for soils and sludges. The extraction procedure is described below:

- A representative sample of 75 g of soil or sludge as received was placed in a previously sterilized mason glass jar.
- 750 ml of sterilized deionized water were added.
- The contents were stirred for 30 min in a chrome-plated mixer with sterilized blades.
- The slurry was allowed to settle.
- An aliquot of the supernatant was pipetted into prepared microbiological tubes for determination of fecal coliform and fecal streptococcus.
- A portion of the supernatant was preserved with several ml of concentrated hydrochloric acid (pH <2) prior to analysis for total organic carbon.
- Aliquots of the supernatant were pipetted separately for the determinations of chemical oxygen demand, total Kjeldahl nitrogen, ammonia, nitrate, chloride, sulfate, and water-soluble mercury. For colorimetric and turbidimetric methods, where turbidity interferes with the determination, a portion of the supernatant was decanted through a fluted filter equivalent to Whatman filter paper No. 42.

- An aliquot of the supernatant was concentrated and analyzed for water-soluble metals.

- An aliquot of the residue was pipetted into a BOD bottle, and analyzed for mercury.

- An equal volume of nitric acid was added to the soil or sludge residue volume remaining in the jar (following water extraction).

- A Teflon-coated stirring bar was placed in an agitating mixer on a hot plate and stirred for approximately 90 min (without boiling).

- Sufficient deionized water was added to the contents to make up to 750 ml.

- Appropriate blanks were prepared for each group of determinations.

Leachate and Groundwater

Leachate and groundwater samples usually were brought back to the laboratory within one to two days after they were collected. Analyses were commenced either immediately or within a few days after sample preparation.

Phase I--

In Phase I the samples were not preserved when collected nor filtered in the laboratory. Sample preparation included:

- A portion of the sample was pipetted and preserved with hydrochloric acid (pH <2) for the analysis of total organic carbon.

- The remaining portion was allowed to settle.

- An aliquot of the supernatant was pipetted into prepared microbiological tubes for determination of fecal coliform and fecal streptococcus.

- The sample was then shaken thoroughly and aliquots were drawn for determination of pH, total solids, total Kjeldahl nitrogen, ammonia, nitrate, chloride, and sulfate.

- An aliquot was pipetted into a BOD bottle and analyzed for mercury.

- A large aliquot was taken and digested in concentrated nitric acid by gently refluxing. This process was repeated several times until a light-colored liquid residue formed. The residue was evaporated gently to dryness, dissolved in 1:1 hydrochloric acid, and diluted with deionized water. The mixture was then filtered, and the filtrate was analyzed for metals.

Phase II--

Two samples were collected from each sample point. One sample was preserved with hydrochloric acid (pH <2) and the other unacidified. Laboratory sample preparation included:

- All samples were filtered through 0.45μ glass-fiber filters before analysis.
- Sample preparation for contaminants other than metals was the same as in Phase I, using unacidified samples.
- For metal analysis, the acidified samples were digested with concentrated nitric and hydrochloric acids and autoclaved at 121°C.
- Aliquots of the acidified samples were pipetted into BOD bottles and analyzed for mercury.

ANALYTICAL PROCEDURES

pH

All pH measurements were performed using an Orion Model 701 pH meter with glass electrode in combination with a saturated calomel reference electrode. The pH meter was standardized periodically under conditions of temperature and pH which were as close as possible to those of the sample, using various standard pH buffer solutions (pH 4, 7, and 10).

Total Solids

The procedure used to determine percent solids was evaporation at 180°C in an air convection oven. Standard Methods (13th Edition, Section 148A, p. 288-289).

Total Organic Carbon

Total organic carbon was determined by the combustion-infrared method. Standard Methods (13th Edition. Section 138A, p. 257).

Chemical Oxygen Demand

Chemical oxygen demand was determined using the dichromate reflux method. Standard Methods (13th Edition, Section 220, p. 495).

Ammonia

Ammonia was analyzed by distillation procedure. Standard Methods (13th Edition, Section 132, p. 222).

Nitrate

Nitrate was determined by the brucine sulfate procedure. Standard Methods (13th Edition, Section 213C, p. 461).

Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen was determined by the classic Kjeldahl digestion procedure. Standard Methods (13th Edition, Section 216, p. 469).

Chloride

Chloride was determined via the mercuric nitrate procedure. Standard Methods (13th Edition, Section 112B, p. 97).

Metals (Calcium, Copper, Chromium, Lead, Iron, Cadmium, Zinc)

Metals were determined by atomic absorption spectrophotometry (AA) according to the techniques in the U.S. EPA Manual of Methods for Chemical Analysis of Water and Wastes, 1974, p. 78. In Phase II, the PDCA extraction procedure was followed for lead determination.

Mercury

Sample digestion and mercury analysis by flameless AA were performed according to the EPA Manual of Methods, p. 118.

APPENDIX E. ANALYTICAL RESULTS FOR PHASE II

TABLE 1A. ANALYTIC RESULTS FOR SITE 1 IN-REFUSE AND ORIGINAL OFF-SITE WELLS (PHASE II)

Sample Date	Constituents*											
	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	Cl	SO_4	TOC	Sp. Cond.
In-Refuse Well												
10/31/76	0.050	0.25	0.13	800.0	0.0002	0.48	0.060	1.2	--	--	--	--
1/21/77	0.050	0.12	0.11	1100.0	<0.0002	0.37	0.700	32.0	230	85	14470	18000
3/10/77	--†	--	--	--	--	--	--	--	--	--	--	--
5/19/77	0.005	0.04	0.02	235.0	--	0.24	0.140	3.2	18	--	2600	--
7/19/77	0.045	0.11	0.13	930.0	<0.0002	0.48	1.280	95.0	92	150	10100	17500†
9/14/77	0.040	0.11	0.09	6.0	<0.0002	0.30	0.680	66.0	153	17	3780	6900
Off-Site Well (OS-X)#												
10/31/76	--	--	--	--	--	--	--	--	--	--	--	--
1/21/77	0.010	<0.01	0.01	7.1	0.0020	0.02	0.090	6.4	70	250	14	1340
3/10/77	--	0.01	0.01	8.3	0.0010	<0.01	--	3.0	52	340	8	1080

*Specific conductance in μmhos/cm, all other constituent concentrations in ppm.

†-- Insufficient sample.

#Well was accidentally removed between the third and fourth samplings.

TABLE 1B. ANALYTICAL RESULTS FOR SITE 1 BACKGROUND WELL (PHASE II)

	Sample Dates					
Constituents*	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Chlorides						
level 1	15	12	6	6	7	10
level 2	35	32	13	6	7	9
level 3	31	83	23	12	13	11
level 4	--†	--	128	33	30	28
Sulfates						
level 1	80	17	17	25	17	22
level 2	260	75	40	40	20	19
level 3	270	165	260	140	105	50
level 4	--	--	260	310	240	200
Total Organic Carbon						
level 1	26	7	4	6	2	2
level 2	16	8	3	11	2	4
level 3	25	5	5	5	3	2
level 4	--	--	12	14	3	5
Specific Conductance						
level 1	--	35	34	--	220	230
level 2	--	1300	41	--	220	190
level 3	--	1380	94	--	460	325
level 4	--	--	98	--	880	810
Cadmium						
level 1	0.001	<0.001	0.001	0.004	<0.001	<0.001
level 2	0.003	<0.001	0.001	0.003	<0.001	<0.001
level 3	0.006	0.008	<0.001	0.005	0.003	<0.001
level 4	--	--	<0.001	0.004	0.007	<0.001
Chromium						
level 1	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
level 2	<0.01	<0.01	0.01	0.01	<0.01	<0.01
level 3	0.01	0.01	<0.01	0.01	0.10	<0.01
level 4	--	--	<0.01	0.06	0.11	<0.01
Copper						
level 1	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
level 2	0.02	<0.01	0.01	0.03	<0.01	<0.01
level 3	0.03	0.06	<0.01	0.08	0.28	<0.01
level 4	--	--	<0.01	<0.01	0.22	<0.01
Iron						
level 1	2.7	61.0	4.9	62.0	15.0	3.9
level 2	4.4	1.5	34.0	71.0	1.0	1.8
level 3	7.3	44.0	11.0	68.0	131.0	0.8
level 4	--	--	0.1	253.0	251.0	3.5

TABLE 1B (continued)

	Sample Dates					
Constituents*	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Mercury						
level 1	0.0002	0.0020	0.0010	0.0022	<0.0002	<0.0002
level 2	0.0005	0.0020	0.0008	0.0026	<0.0002	<0.0002
level 3	< 0.0002	0.0010	0.0010	<0.0002	<0.0002	<0.0002
level 4	-- †	--	0.0010	<0.0002	<0.0002	<0.0002
Nickel						
level 1	0.02	0.07	0.05	0.09	<0.01	<0.01
level 2	0.06	0.01	0.03	0.08	<0.01	<0.01
level 3	0.12	0.18	0.02	0.13	0.06	<0.01
level 4	--	--	0.08	0.14	0.10	<0.01
Lead						
level 1	0.020	0.070	0.020	0.020	0.005	<0.005
level 2	0.040	<0.005	0.070	0.190	<0.005	0.010
level 3	0.060	0.130	0.020	0.210	0.098	<0.005
level 4	--	--	0.005	0.110	--	<0.005
Zinc						
level 1	0.14	0.15	0.04	0.28	0.08	0.07
level 2	0.25	0.04	0.18	0.43	0.06	0.08
level 3	0.36	0.47	0.05	0.56	1.30	0.01
level 4	--	--	< 0.01	3.70	3.80	0.07

*Constituent concentrations in ppm.

†-- Insufficient sample.

TABLE 1C. CHLORIDE ANALYTICAL RESULTS FOR SITE 1 OFF-SITE WELLS (PHASE II)*

	Sample Dates					
	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Offsite Well No. 1						
level 1	25	131	6	11	6	7
level 2	29	24	16	15	15	16
level 3	--†	--	--	--		--
level 4	34	--	28	43	28	30
Offsite Well No. 2						
level 1	32	28	329	5	5	8
level 2	40	17	21	10	10	9
level 3	35	31	21	24	26	27
level 4	30	29	27	26	24	28
Offsite Well No. 3						
level 1	27	--	--	--	5	--
level 2	29	--	26	--	21	13
level 3	54	27	17	8	7	6
level 4	--	--	15	28	27	29
Offsite Well No. 4						
level 1	30	--	2	42	36	22
level 2	34	--	< 2	43	24	29
level 3	29	12	24	30	26	28
level 4	57	65	< 2	44	27	26
Offsite Well No. 5						
level 1	31	52	13	<2	<2	< 2
level 2	30	38	3	12	12	< 2
level 3	29	--	5	23	11	6
level 4	57	56	24	33	26	29
Offsite Well No. 6						
level 1	34	--	13	--	--	--
level 2	31	37	6	4	6	5
level 3	31	--	20	13	--	6
level 4	35	--	33	27	27	29

*Concentrations in ppm.

†-- Insufficient sample.

TABLE 1D. SULFATE ANALYTICAL RESULTS FOR FOR SITE 1 OFF-SITE WELLS (PHASE II)*

Location	Sample Dates					
	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Offsite Well No. 1						
level 1	200	40	6	35	30	24
level 2	220	100	15	115	100	66
level 3	--†	--	--	--	--	--
level 4	224	--	20	290	250	195
Offsite Well No. 2						
level 1	320	280	90	35	25	41
level 2	320	210	130	100	115	67
level 3	--	350	300	265	250	170
level 4	270	130	250	250	230	185
Offsite Well No. 3						
level 1	--	--	--	--	30	--
level 2	270	--	260	--	190	120
level 3	230	130	180	80	60	42
level 4	250	--	250	275	270	230
Offsite Well No. 4						
level 1	210	--	4	325	190	60
level 2	250	--	6	275	200	65
level 3	230	1	210	275	215	120
level 4	260	100	55	250	215	105
Offsite Well No. 5						
level 1	270	110	20	50	15	18
level 2	220	35	40	60	40	26
level 3	220	--	70	175	200	50
level 4	200	110	190	215	225	75
Offsite Well No. 6						
level 1	370	--	175	--	--	--
level 2	310	90	85	35	35	30
level 3	270	--	250	140	--	50
level 4	230	--	250	250	265	240

* Concentrations in ppm.

† -- Insufficient sample.

TABLE 1E. TOTAL ORGANIC CARBON ANALYTICAL RESULTS FOR SITE 1 OFF-SITE WELLS (PHASE II)[*]

	Sample Dates					
	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Offsite Well No. 1						
level 1	25	5	4	3	4	3
level 2	48	6	5	4	3	5
level 3	--[†]	--	--	--	--	--
level 4	44	--	4	3	4	3
Offsite Well No. 2						
level 1	46	7	2	2	2	1
level 2	4	4	3	2	4	<1
level 3	18	4	5	3	3	2
level 4	19	3	5	6	3	2
Offsite Well No. 3						
level 1	20	--	--	--	4	--
level 2	32	--	4	--	3	3
level 3	37	5	3	3	2	1
level 4	30	--	3	6	3	5
Offsite Well No. 4						
level 1	88	--	91	5	3	3
level 2	107	--	260	6	3	2
level 3	82	154	7	6	2	4
level 4	73	8	9	6	4	3
Offsite Well No. 5						
level 1	171	264	50	8	5	4
level 2	381	77	72	2	4	8
level 3	144	--	16	5	4	3
level 4	81	21	4	3	3	<1
Offsite Well No. 6						
level 1	--	--	5	--	--	--
level 2	11	4	1	6	5	3
level 3	25	--	5	3	--	3
level 4	7	--	3	5	4	3

[*] Concentrations in ppm.

[†] -- Insufficient sample.

TABLE 1F . CADMIUM ANALYTICAL RESULTS FOR SITE 1 OFF-SITE WELLS (PHASE II)*

	Sample Dates					
	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Offsite Well No. 1						
level 1	<0.001	<0.001	--	0.002	<0.001	<0.001
level 2	<0.001	0.001	--	0.001	<0.001	<0.001
level 3	--†	--	--	--	--	--
level 4	<0.001	--	<0.001	0.004	<0.001	<0.001
Offsite Well No. 2						
level 1	0.010	0.001	0.010	0.004	0.002	<0.001
level 2	0.010	<0.001	0.001	0.004	0.001	<0.001
level 3	<0.001	0.008	0.010	0.007	0.010	<0.001
level 4	<0.001	<0.001	<0.001	0.001	<0.001	<0.001
Offsite Well No. 3						
level 1	<0.001	--	--	--	<0.001	--
level 2	<0.001	--	<0.001	--	0.004	0.016
level 3	0.002	<0.001	<0.001	0.004	0.002	<0.001
level 4	<0.001	--	<0.001	0.001	<0.001	<0.001
Offsite Well No. 4						
level 1	<0.001	--	<0.001	0.003	<0.001	<0.001
level 2	0.002	--	<0.001	0.001	0.005	<0.001
level 3	0.001	<0.001	<0.001	0.004	<0.001	<0.001
level 4	<0.001	<0.001	<0.001	0.002	<0.001	<0.001
Offsite Well No. 5						
level 1	0.001	<0.001	<0.001	0.001	<0.001	<0.001
level 2	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
level 3	<0.001	--	<0.001	<0.001	<0.001	<0.001
level 4	0.001	<0.001	<0.001	--	<0.001	<0.001
Offsite Well No. 6						
level 1	<0.001	--	--	--	--	--
level 2	<0.001	<0.001	<0.001	0.003	0.004	<0.001
level 3	0.020	--	<0.001	0.001	--	<0.001
level 4	0.010	--	<0.001	<0.001	0.004	<0.001

* Concentrations in ppm.

† -- Insufficient sample.

TABLE 1G . CHROMIUM ANALYTICAL RESULTS FOR SITE 1 OFF-SITE WELLS (PHASE II)*

	Sample Dates					
	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Offsite Well No. 1						
level 1	<0.01	<0.01	<0.01	0.01	<0.01	0.01
level 2	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
level 3	--†	--	--	--	--	--
level 4	<0.01	--	<0.01	0.01	<0.01	<0.01
Offsite Well No. 2						
level 1	0.01	<0.01	0.01	0.01	0.04	<0.01
level 2	<0.01	<0.01	0.01	0.01	<0.01	<0.01
level 3	0.01	0.02	0.02	0.03	0.04	<0.01
level 4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Offsite Well No. 3						
level 1	<0.01	--	--	<0.01	0.01	--
level 2	<0.01	--	0.01	0.01	0.06	0.07
level 3	<0.01	<0.01	<0.01	0.02	0.01	<0.01
level 4	<0.01	--	<0.01	0.01	<0.01	<0.01
Offsite Well No. 4						
level 1	<0.01	--	<0.01	0.01	<0.01	<0.01
level 2	<0.01	--	<0.01	0.01	<0.01	<0.01
level 3	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
level 4	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Offsite Well No. 5						
level 1	<0.01	<0.01	<0.01	0.02	<0.01	<0.01
level 2	<0.01	0.01	<0.01	0.02	<0.01	<0.01
level 3	<0.01	--	<0.01	0.01	<0.01	<0.01
level 4	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Offsite Well No. 6						
level 1	<0.01	--	--	<0.01	--	--
level 2	<0.01	<0.01	<0.01	0.01	0.10	<0.01
level 3	0.04	--	<0.01	0.01	<0.01	<0.01
level 4	0.03	--	<0.01	<0.01	0.05	<0.01

* Concentrations in ppm.

† -- Insufficient sample.

TABLE 1H. COPPER ANALYTICAL RESULTS FOR SITE 1 OFF-SITE WELLS (PHASE II)*

	Sample Dates					
	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Offsite Well No. 1						
level 1	<0.01	<0.01	0.01	0.01	<0.01	0.01
level 2	<0.01	<0.01	<0.01	0.03	<0.01	<0.01
level 3	--†	--	--	--	--	--
level 4	<0.01	--	<0.01	0.01	<0.01	<0.01
Offsite Well No. 2						
level 1	0.08	<0.01	0.08	0.05	0.12	<0.01
level 2	0.01	<0.01	0.01	0.06	<0.01	<0.01
level 3	<0.01	0.07	0.09	0.12	0.10	<0.01
level 4	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Offsite Well No. 3						
level 1	<0.01	--	--	<0.01	0.01	--
level 2	<0.01	--	0.01	0.01	0.12	0.24
level 3	0.02	<0.01	<0.01	0.07	0.02	<0.01
level 4	<0.01	--	<0.01	0.02	<0.01	<0.01
Offsite Well No. 4						
level 1	<0.01	--	<0.01	<0.01	<0.01	<0.01
level 2	0.01	--	<0.01	<0.01	<0.01	<0.01
level 3	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
level 4	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Offsite Well No. 5						
level 1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
level 2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
level 3	<0.01	--	<0.01	<0.01	<0.01	<0.01
level 4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Offsite Well No. 6						
level 1	<0.01	--	--	<0.01	--	--
level 2	<0.01	<0.01	<0.01	0.03	0.13	<0.01
level 3	0.03	--	<0.01	0.01	0.01	<0.01
level 4	0.04	--	<0.01	<0.01	0.05	<0.01

* Concentrations in ppm.

† -- Insufficient sample.

TABLE 11 . IRON ANALYTICAL RESULTS FOR FOR SITE 1 OFF-SITE WELLS (PHASE II)*

	Sample Dates					
	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Offsite Well No. 1						
level 1	1.50	<0.01	3.30	6.80	<0.01	16.00
level 2	<0.01	0.01	4.60	39.00	0.16	0.41
level 3	--[†]	--	--	--	--	--
level 4	2.20	-	2.40	15.00	0.01	4.30
Offsite Well No. 2						
level 1	23.00	0.10	23.00	27.00	41.00	2.10
level 2	5.50	<0.01	6.10	36.00	11.00	3.70
level 3	<0.01	16.00	23.00	47.00	59.00	5.20
level 4	0.09	2.00	<0.01	26.00	1.20	0.07
Offsite Well No. 3						
level 1	0.04	--	--	0.50	0.43	--
level 2	<0.01	--	8.30	12.00	41.00	30.00
level 3	4.60	0.24	5.80	24.00	19.00	3.00
level 4	2.40	--	0.01	25.00	1.20	0.14
Offsite Well No. 4						
level 1	0.38	--	1.00	135.00	15.00	8.80
level 2	3.50	--	5.00	139.00	51.00	12.00
level 3	8.00	2.70	2.20	134.00	12.00	6.90
level 4	7.20	47.00	13.00	152.00	8.50	5.60
Offsite Well No. 5						
level 1	0.39	7.40	1.60	45.00	1.60	2.60
level 2	0.13	1.30	1.00	31.00	1.20	1.60
level 3	0.64	--	1.40	16.00	0.77	0.06
level 4	1.10	0.66	0.32	9.00	1.10	0.34
Offsite Well No. 6						
level 1	0.25	--	--	0.84	--	--
level 2	<0.01	<0.01	0.90	14.00	78.00	0.61
level 3	8.10	--	0.44	12.00	5.90	0.14
level 4	16.00	--	0.05	2.70	35.60	0.74

* Concentration in ppm.

[†] -- Insufficient sample.

TABLE 1J. MERCURY ANALYTICAL RESULTS FOR SITE 1 OFF-SITE WELLS (PHASE II)*

	Sample Dates					
	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Offsite Well No. 1						
level 1	0.0002	0.0020	0.0009	<0.0002	<0.0002	<0.0002
level 2	<0.0002	0.0005	0.0004	<0.0002	<0.0002	0.0035
level 3	--†	--	--	--	--	--
level 4	<0.0002	--	0.0005	<0.0002	<0.0002	0.0095
Offsite Well No. 2						
level 1	0.0003	0.0003	<0.0002	0.0017	<0.0002	0.0047
level 2	0.0002	<0.0002	0.0006	<0.0002	<0.0002	0.0024
level 3	<0.0002	<0.0002	0.0008	<0.0002	<0.0002	0.0072
level 4	0.0003	<0.0002	0.0006	<0.0002	<0.0002	0.0065
Offsite Well No. 3						
level 1	0.0003	--	--	<0.0002	<0.0002	--
level 2	0.0002	--	0.0010	0.0007	<0.0002	0.0033
level 3	0.0005	<0.0002	0.0010	0.0004	<0.0002	<0.0002
level 4	<0.0002	--	0.0006	0.0006	<0.0002	0.0014
Offsite Well No. 4						
level 1	<0.0020	--	0.0006	0.0005	<0.0002	<0.0002
level 2	<0.0002	--	0.0020	0.0005	<0.0002	<0.0002
level 3	0.0002	<0.0002	0.0020	0.0010	<0.0002	<0.0002
level 4	<0.0002	0.0009	0.0010	0.0004	0.0008	<0.0002
Offsite Well No. 5						
level 1	0.0003	0.0007	0.0004	0.0002	<0.0002	<0.0002
level 2	<0.0002	<0.0002	0.0007	0.0005	<0.0002	<0.0002
level 3	<0.0002	--	0.0005	<0.0002	<0.0002	0.0018
level 4	<0.0002	<0.0002	0.0005	<0.0002	<0.0002	0.0017
Offsite Well No. 6						
level 1	0.0003	--	--	--	--	--
level 2	0.0003	0.0002	0.0004	<0.0002	0.0003	<0.0002
level 3	<0.0002	--	0.0003	<0.0002	0.0004	<0.0002
level 4	<0.0002	--	0.0004	<0.0002	0.0002	<0.0002

* Concentrations in ppm.

† -- Insufficient sample.

TABLE 1K. NICKEL ANALYTICAL RESULTS FOR SITE 1 OFF-SITE WELLS (PHASE II)*

	Sample Dates					
	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Offsite Well No. 1						
level 1	<0.01	0.09	<0.01	0.08	<0.01	0.05
level 2	<0.01	<0.01	<0.01	0.04	<0.01	<0.01
level 3	--†	--	--	--	--	--
level 4	0.02	--	<0.01	0.11	<0.01	0.01
Offsite Well No. 2						
level 1	0.12	0.01	0.16	0.12	0.02	<0.01
level 2	0.12	<0.01	<0.01	0.11	0.02	0.01
level 3	0.02	0.29	0.20	0.19	0.17	0.01
level 4	<0.01	0.01	<0.01	0.05	<0.01	<0.01
Offsite Well No. 3						
level 1	<0.01	--	--	<0.01	<0.01	--
level 2	0.01	--	0.01	<0.01	0.11	0.26
level 3	0.03	<0.01	0.01	0.25	0.04	<0.01
level 4	0.01	--	<0.01	0.11	<0.01	<0.01
Offsite Well No. 4						
level 1	<0.01	--	<0.01	0.21	<0.01	<0.01
level 2	0.01	--	<0.01	0.23	0.04	<0.01
level 3	0.02	<0.01	<0.01	0.08	<0.01	<0.01
level 4	0.01	0.02	<0.01	0.08	<0.01	<0.01
Offsite Well No. 5						
level 1	0.01	0.03	<0.01	0.09	<0.01	<0.01
level 2	<0.01	<0.01	<0.01	0.05	<0.01	<0.01
level 3	<0.01	--	<0.01	0.02	<0.01	<0.01
level 4	0.01	<0.01	<0.01	0.03	<0.01	<0.01
Offsite Well No. 6						
level 1	0.02	--	--	<0.01	--	--
level 2	<0.01	<0.01	<0.01	0.07	0.09	<0.01
level 3	0.21	--	<0.01	0.04	0.01	<0.01
level 4	0.09	--	<0.01	<0.01	0.07	<0.01

* Concentrations in ppm.

† -- Insufficient sample.

TABLE 1L . LEAD ANALYTICAL RESULTS
FOR SITE 1 OFF-SITE WELLS (PHASE II)*

	Sample Dates					
	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Offsite Well No. 1						
level 1	0.030	<0.005	--	0.730	<0.005	0.183
level 2	0.030	0.006	--	0.100	<0.005	<0.005
level 3	--†	--	--	--	--	--
level 4	0.040	--	0.010	0.340	<0.005	0.005
Offsite Well No. 2						
level 1	0.020	<0.005	0.170	0.280	0.051	<0.005
level 2	0.050	<0.005	0.050	0.320	0.047	0.015
level 3	0.010	0.380	0.360	0.330	0.280	0.009
level 4	<0.005	0.070	<0.005	0.130	<0.005	<0.005
Offsite Well No. 3						
level 1	<0.005	--	--	--	<0.005	--
level 2	<0.005	--	0.020	--	0.190	0.530
level 3	0.050	<0.005	0.030	0.245	0.074	<0.005
level 4	0.020	--	<0.005	0.105	<0.005	<0.005
Offsite Well No. 4						
level 1	<0.005	--	<0.005	0.045	<0.005	<0.005
level 2	0.020	--	<0.005	0.030	0.014	<0.005
level 3	0.060	<0.005	<0.005	0.100	<0.005	<0.005
level 4	0.010	<0.005	0.009	0.055	<0.005	<0.005
Offsite Well No. 5						
level 1	<0.005	<0.005	<0.005	0.125	<0.005	<0.005
level 2	<0.005	<0.005	<0.005	0.120	<0.005	<0.005
level 3	<0.005	--	<0.005	0.035	<0.005	<0.005
level 4	<0.005	<0.005	<0.005	--	<0.005	<0.005
Offsite Well No. 6						
level 1	<0.005	--	--	--	--	--
level 2	<0.005	<0.005	0.005	0.275	0.340	<0.005
level 3	0.210	--	<0.005	0.135	--	<0.005
level 4	0.210	--	<0.005	0.005	0.255	<0.005

* Concentration in ppm.

† -- Insufficient sample.

TABLE 1M . ZINC ANALYTICAL RESULTS
FOR SITE 1 OFF-SITE WELLS (PHASE II)*

	Sample Dates					
	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Offsite Well No. 1						
level 1	0.08	0.01	0.06	0.10	0.01	0.15
level 2	0.23	0.01	0.06	0.46	0.01	0.21
level 3	--†	--	--	--	--	--
level 4	0.14	--	0.03	0.12	0.07	0.05
Offsite Well No. 2						
level 1	1.80	0.58	0.95	0.45	1.20	0.05
level 2	0.63	<0.01	0.18	0.40	0.10	0.07
level 3	0.03	0.87	0.72	0.65	0.54	0.07
level 4	0.01	0.04	<0.01	0.23	0.02	0.04
Offsite Well No. 3						
level 1	<0.01	--	--	0.01	0.83	--
level 2	0.11	--	2.00	3.90	24.00	95.00
level 3	0.35	0.01	0.14	1.00	0.28	0.03
level 4	0.13	--	0.02	0.25	0.02	0.04
Offsite Well No. 4						
level 1	0.03	--	0.01	0.55	0.07	0.03
level 2	0.06	--	0.02	0.56	0.19	0.04
level 3	0.11	0.01	0.03	0.48	0.01	0.02
level 4	0.17	<0.01	0.04	0.53	<0.01	0.09
Offsite Well No. 5						
level 1	0.05	0.01	0.01	0.37	<0.01	0.01
level 2	0.16	0.01	0.02	0.22	0.01	0.06
level 3	0.05	--	0.02	0.13	0.03	0.06
level 4	0.01	0.01	0.01	0.38	0.04	0.01
Offsite Well No. 6						
level 1	0.04	--	--	0.03	--	--
level 2	<0.01	<0.01	0.01	0.28	1.20	0.07
level 3	0.71	--	0.03	1.50	0.04	0.13
level 4	0.48	--	0.03	0.05	0.50	0.02

*Concentration in ppm.

† -- Insufficient sample.

TABLE 1N. SPECIFIC CONDUCTANCE ANALYTICAL RESULTS FOR SITE 1 OFF-SITE WELLS (PHASE II)*

	Sample Dates					
	10/31/76	1/21/77	3/10/77	5/19/77	7/19/77	9/14/77
Off-Site Well No. 1						
level 1	--†	44	33	--	380	380
level 2	--	55	50	--	570	560
level 3	--	--	--	--	--	--
level 4	--	--	66	--	920	810
Off-Site Well No. 2						
level 1	--	75	87	--	300	380
level 2	--	62	54	--	480	360
level 3	--	73	79	--	1020	840
level 4	--	60	67	--	880	820
Off-Site Well No. 3						
level 1	--	--	--	--	350	--
level 2	--	--	63	--	620	510
level 3	--	58	51	--	380	360
level 4	--	--	68	--	990	850
Off-Site Well No. 4						
level 1	--	--	81	--	900	680
level 2	--	--	106	--	970	880
level 3	--	--	66	--	870	790
level 4	--	76	68	--	870	800
Off-Site Well No. 5						
level 1	--	1120	51	--	880	1060
level 2	--	54	44	--	530	660
level 3	--	--	71	--	940	810
level 4	--	70	64	--	920	840
Off-Site Well No. 6						
level 1	--	--	57	--	--	--
level 2	--	1580	31	--	290	280
level 3	--	--	66	--	--	320
level 4	--	--	66	--	920	820

* Specific conductance in μmhos/cm.

† -- Insufficient sample.

TABLE 2. ANALYTICAL RESULTS FOR SITE 2, PHASE II

Sample Date	Constituents*											
	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	Cl	SO_4	TOC	Sp. Cond.
Background Well												
11/1/76	0.001	<0.01	<0.01	0.42	<0.0002	<0.01	0.130	0.11	180	90	89	--†
1/21/77	0.003	<0.01	<0.01	0.94	0.0020	<0.01	0.019	1.20	191	35	10	190
3/10/77	--	--	--	--	--	--	--	--	--	--	--	--
5/18/77	<0.001	<0.01	<0.01	0.59	<0.0002	<0.01	0.019	0.13	26	50	3	--
7/18/77	<0.001	<0.01	<0.01	1.20	<0.0004	<0.01	0.014	0.09	25	70	2	1360
9/13/77	<0.002	<0.01	<0.01	0.76	0.0004	0.01	0.037	0.08	75	97	12	610
In-Refuse Well												
11/1/76	0.005	0.03	0.03	5.50	<0.0002	0.16	1.400	0.32	61#	950	520	--
1/21/77	0.010	0.04	0.03	1.90	<0.0002	--	0.150	1.40	70	1250	451	850
3/10/77	--	--	--	--	--	--	--	--	--	--	--	700
5/18/77	0.005	0.04	<0.01	1.20	<0.0002	0.20	0.240	0.18	4	1290	346	--
7/18/77	<0.005	0.02	<0.01	1.50	0.0002	0.12	0.440	0.06	576	1400	318	7500
9/13/77	0.020	0.03	0.03	1.70	0.00025	0.09	0.370	0.20	4	723	148	4400
Deep Off-Site Well (OS-2)												
11/1/76	0.007	0.01	<0.01	4.40	0.0130	<0.01	1.500	0.08	68	160	99	--
1/21/77	<0.001	<0.01	<0.01	2.10	0.0040	<0.01	0.075	7.90	47	160	52	3000
3/10/77	--	--	--	--	--	--	--	--	--	--	--	250
5/18/77	<0.001	<0.01	<0.01	1.96	0.0003	<0.01	0.121	0.14	9	270	13	--
7/18/77	0.001	0.01	0.01	1.10	0.0005	<0.01	0.150	0.22	43	230	16	2900
9/13/77	<0.001	0.01	<0.01	1.10	0.0027	<0.01	0.126	0.15	15	76	19	1150

*Specific conductance in μmhos/cm, all other constituents concentrations in ppm.

†-- Insufficient sample.

Possible interference.

TABLE 3A. ANALYTICAL RESULTS FOR SITE 3
IN-REFUSE AND ORIGINAL OFF-SITE WELLS (PHASE II)

Sample Date	Constituents*											
	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	Cl	SO_4	TOC	Sp. Cond.
In-Refuse Well												
11/1/76	0.005	0.12	0.01	6.5	<0.0002	0.02	0.150	0.16	12	20#	2240	--†
1/20/77	0.005	0.46	0.02	9.1	<0.0002	0.30	0.065	1.80	26	4	2028	25000
3/8/77	0.003	0.07	0.03	15.0	0.0010	0.28	0.470	0.41	30	12	1790	24000
5/16/77	0.005	0.06	0.01	17.0	0.0003	0.08	0.240	0.65	<2	30	8	--
7/18/77	<0.005	0.01	<0.01	24.8	0.0002	0.05	0.140	<0.01	19	70	70	7500
9/12/77	0.010	0.01	<0.01	16.0	0.0002	0.04	0.090	0.10	11	33	76	8000
Off-Site Well (OS-X)												
11/1/76	0.005	<0.01	0.04	14.0	0.0005	0.10	0.090	0.44	1	50	166	--
1/20/77	0.005	0.01	0.05	40.0	0.0002	0.15	0.120	1.90	<2	20	4	180
3/8/77	0.005	0.01	0.10	23.0	0.0040	0.13	0.270	0.48	1	30	3	130
5/16/77	0.007	0.01	<0.12	28.5	0.0005	0.10	1.900	0.60	<2	30	18	--
7/18/77	0.015	0.06	0.28	86.0	0.0003	0.21	0.310	1.10	<2	30	7	1500
9/12/77	0.002	<0.01	<0.01	2.2	<0.0002	0.02	0.037	.09	<2	25	5	1130

*Specific conductance in µmhos/cm, all other constituents concentrations in ppm.

†--Insufficient sample.

Possible interference.

TABLE 3B. ANALYTICAL RESULTS FOR SITE 3 BACKGROUND WELL (PHASE II)

Constituents*	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Chlorides						
level 1	24	146	<2	<2	< 2	<2
level 2	21	19	<2	<2	< 2	<2
level 3	70	14	<2	--†	< 2	<2
level 4	16	4	--	<2	< 2	<2
Sulfates						
level 1	60	40	25	75	90	79
level 2	50	25	20	45	30	23
level 3	87	40	17	3	2	3
level 4	50	4	--	5	1	4
Total Organic Carbon						
level 1	110	6	16	6	7	2
level 2	99	5	15	7	7	13
level 3	--	8	9	9	9	3
level 4	126	4	--	7	9	13
Specific Conductance						
level 1	--	110	87	--	1150	960
level 2	--	97	88	--	1100	880
level 3	--	85	2400	--	750	700
level 4	--	72	--	--	750	710
Cadmium						
level 1	0.001	<0.001	0.015	0.015	0.016	<0.001
level 2	<0.001	<0.001	<0.001	0.013	<0.001	0.001
level 3	<0.001	0.002	0.003	0.002	0.002	0.003
level 4	<0.001	<0.001	--	0.004	<0.001	0.001
Chromium						
level 1	<0.01	<0.01	0.06	0.01	0.07	<0.01
level 2	<0.01	<0.01	<0.01	0.02	< 0.01	<0.01
level 3	<0.01	0.02	0.03	<0.01	< 0.01	<0.01
level 4	<0.01	<0.01	--	0.02	< 0.01	<0.01
Copper						
level 1	<0.01	<0.01	0.01	<0.01	0.10	<.01
level 2	<0.01	<0.01	<0.01	0.05	< 0.01	<.01
level 3	<0.01	<0.01	0.04	0.01	< 0.01	<.01
level 4	0.02	<0.01	--	0.03	< 0.01	<.01
Iron						
level 1	111.0	10.0	280.0	263.0	137.0	7.2
level 2	<0.0	6.3	6.1	83.0	7.3	8.7
level 3	0.0	85.0	60.0	19.0	23.0	32.0
level 4	42.0	9.2	--	47.0	9.3	12.0

TABLE 3B (continued)

Constituent*	Sample Dates 11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Mercury						
level 1	0.0003	<0.0002	0.0030	0.0003	<0.0002	0.0065
level 2	<0.0002	0.0005	0.0080	0.0004	<0.0002	<0.0002
level 3	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
level 4	<0.0002	<0.0002	--[†]	<0.0002	<0.0002	0.0012
Nickel						
level 1	0.05	<0.01	0.61	0.57	0.22	<0.01
level 2	<0.01	<0.01	0.01	0.15	<0.01	<0.01
level 3	<0.01	0.12	0.48	0.02	0.02	0.03
level 4	<0.01	<0.01	--	0.08	<0.01	<0.01
Lead						
level 1	<0.005	<0.005	0.250	0.063	0.180	<0.005
level 2	<0.005	<0.005	0.010	0.093	<0.005	<0.005
level 3	<0.005	0.047	0.080	0.008	0.015	0.016
level 4	0.040	<0.005	--	0.033	<0.005	<0.005
Zinc						
level 1	0.10	0.02	1.40	0.93	0.78	0.02
level 2	0.01	<0.01	<0.01	0.40	0.01	0.16
level 3	0.01	0.29	0.33	0.57	0.05	0.12
level 4	0.41	0.01	--	0.38	0.01	0.08

*Constituent concentrations in ppm.

[†]-- Insufficient sample.

TABLE 3C . CHLORIDE ANALYTICAL RESULTS FOR SITE 3 OFFSITE WELLS (PHASE II)*

	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Offsite Well No. 1						
level 1	--†	100	1	<2	<2	<2
level 2	99	96	1	<2	<2	<2
level 3	74	98	< 2	<2	<2	<2
level 4	115	--	--	--	--	--
Offsite Well No. 2						
level 1	2	1510	< 2	<2	<2	<2
level 2	2	< 2	< 2	<2	<2	<2
level 3	120	38	< 2	<2	<2	<2
level 4	57	58	< 2	<2	<2	2
Offsite Well No. 3						
level 1	99	< 2	< 2	<2	<2	< 2
level 2	100	140	< 2	<2	<2	< 2
level 3	110	94	< 2	<2	<2	< 2
level 4	3600	142	--	--	--	--
Offsite Well No. 4						
level 1	100	27	3	<2	<2	4
level 2	58	33	4	<2	<2	4
level 3	95	119	3	<2	<2	2
level 4	88	94	--	--	--	--
Offsite Well No. 5						
level 1	97	82	2	<2	2	15
level 2	--	86	--	51	--	27
level 3	96	126	66	20	7	12
level 4	36	24	< 2	<2	<2	5
Offsite Well No. 6						
level 1	110	88	< 2	<2	<2	<2
level 2	63	52	< 2	<2	<2	<2
level 3	90	83	8	<2	2	<2
level 4	84	79	4	<2	3	2

*Concentrations in ppm.

†-- Insufficient sample.

TABLE 3D. SULFATE ANALYTICAL RESULTS FOR SITE 3 OFFSITE WELLS (PHASE II)[*]

	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Offsite Well No. 1						
level 1	--[†]	175	150	110	90	61
level 2	240	225	170	100	125	100
level 3	160	160	125	85	70	58
level 4	--	--	--	--	--	--
Offsite Well No. 2						
level 1	25	1	3	3	2	3
level 2	25	83	1	1	1	1
level 3	25	50	30	110	45	113
level 4	30	45	35	160	45	45
Offsite Well No. 3						
level 1	200	8	3	45	15	33
level 2	200	180	150	90	65	65
level 3	210	160	90	85	65	72
level 4	200	100	--	--	--	--
Offsite Well No. 4						
level 1	140	50	40	45	40	30
level 2	110	60	50	45	35	30
level 3	140	115	75	50	50	35
level 4	125	165	--	--	--	--
Offsite Well No. 5						
level 1	130	115	50	55	60	33
level 2		125		150	--	55
level 3	130	110	115	65	40	34
level 4	80	75	50	40	4	17
Offsite Well No. 6						
level 1	125	45	55	30	30	28
level 2	80	85	85	85	35	40
level 3	150	160	140	105	85	61
level 4	130	125	85	100	85	66

[*] Concentrations in ppm.

[†] -- Insufficient sample.

TABLE 3E. TOTAL ORGANIC CARBON ANALYTICAL RESULTS FOR SITE 3 OFFSITE WELLS (PHASE II)*

	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Offsite Well No. 1						
level 1	--[†]	38	5	11	9	3
level 2	114	42	3	9	8	3
level 3	55	9	6	8	3	4
level 4	--	--	--	--	--	--
Offsite Well No. 2						
level 1	176	35	27	24	17	22
level 2	158	34	14	26	24	23
level 3	35	10	16	7	6	3
level 4	68	11	8	8	5	5
Offsite Well No. 3						
level 1	94	185	97	19	39	31
level 2	70	61	24	19	26	20
level 3	46	26	8	12	7	5
level 4	--	30	--	--	--	--
Offsite Well No. 4						
level 1	35	6	5	7	4	3
level 2	30	8	6	6	3	2
level 3	167	3	8	7	6	2
level 4	14	4	--	--	--	--
Offsite Well No. 5						
level 1	14	1	8	10	6	3
level 2	--	5	--	7	--	3
level 3	135	2	4	7	4	3
level 4	181	2	4	9	5	4
Offsite Well No. 6						
level 1	18	19	4	15	4	2
level 2	32	6	3	13	4	4
level 3	106	6	2	9	4	3
level 4	9	7	5	12	6	5

* Concentrations in ppm.

[†] -- Insufficient sample.

TABLE 3F. CADMIUM ANALYTICAL RESULTS FOR SITE 3 OFFSITE WELLS (PHASE II)[*]

	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Offsite Well No. 1						
level 1	--[†]	<0.001	<0.001	<0.001	<0.001	<0.001
level 2	<0.001	0.006	<0.001	0.020	0.003	<0.001
level 3	0.030	0.002	<0.001	0.002	0.001	0.002
level 4	0.008	--	--	--	--	--
Offsite Well No. 2						
level 1	<0.001	0.003	--	0.005	0.002	--
level 2	<0.001	0.001	<0.001	--	<0.001	<0.001
level 3	<0.001	<0.001	--	<0.001	0.001	<0.001
level 4	<0.002	<0.001	--	<0.001	<0.001	<0.001
Offsite Well No. 3						
level 1	0.020	<0.001	<0.001	0.002	0.001	0.002
level 2	<0.001	0.001	0.002	0.006	<0.001	0.002
level 3	<0.001	0.002	0.003	0.008	0.011	0.002
level 4	--	<0.001	--	--	--	--
Offsite Well No. 4						
level 1	0.020	<0.001	<0.001	0.006	<0.001	0.002
level 2	0.010	0.006	<0.001	0.006	0.003	<0.001
level 3	0.010	0.008	0.001	0.011	0.008	0.002
level 4	0.001	<0.001	--	--	--	--
Offsite Well No. 5						
level 1	0.020	<0.001	--	0.017	0.009	0.001
level 2	0.010	0.012	--	--	--	0.022
level 3	0.010	0.006	<0.001	--	0.008	<0.001
level 4	0.020	0.018	0.020	0.013	0.023	0.022
Offsite Well No. 6						
level 1	0.010	0.001	<0.001	0.004	0.002	<0.001
level 2	0.020	<0.001	0.002	0.005	0.002	0.014
level 3	0.002	0.001	--	0.006	0.031	0.010
level 4	0.003	<0.001	<0.001	0.015	0.015	0.007

[*] Concentrations in ppm.

[†] -- Insufficient sample.

TABLE 3G . CHROMIUM ANALYTICAL RESULTS FOR SITE 3 OFFSITE WELLS (PHASE II)*

	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Offsite Well No. 1						
level 1	--[†]	<0.01	<0.01	<0.01	<0.01	<0.01
level 2	<0.01	0.01	<0.01	0.03	<0.01	<0.01
level 3	0.05	<0.01	<0.01	0.04	0.01	<0.01
level 4	0.01	--	--	--	--	--
Offsite Well No. 2						
level 1	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
level 2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
level 3	<0.01	<0.01	0.09	0.02	<0.01	<0.01
level 4	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Offsite Well No. 3						
level 1	<0.01	<0.01	<0.01	0.01	<0.01	0.01
level 2	<0.01	<0.01	<0.01	0.06	<0.01	0.01
level 3	<0.01	0.01	0.01	0.06	0.06	0.01
level 4	--	<0.01	--	--	--	--
Offsite Well No. 4						
level 1	0.04	<0.01	0.01	0.01	<0.01	<0.01
level 2	0.03	<0.01	<0.01	0.02	0.01	0.01
level 3	<0.01	0.01	<0.01	0.04	0.04	0.01
level 4	<0.01	<0.01	--	--	--	--
Offsite Well No. 5						
level 1	0.03	<0.01	0.01	0.04	0.03	0.01
level 2	0.24	0.02	--	--	0.22	0.07
level 3	0.02	0.01	<0.01	0.09	0.03	0.06
level 4	0.03	0.01	0.06	<0.01	0.02	0.08
Offsite Well No. 6						
level 1	0.01	0.01	<0.01	0.12	<0.01	<0.01
level 2	0.01	<0.01	0.01	0.05	<0.01	0.05
level 3	<0.01	0.01	0.04	0.06	0.04	0.03
level 4	0.01	<0.01	<0.01	0.03	0.06	0.02

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[*] Concentrations in ppm.

[†] -- Insufficient sample.

TABLE 3H . COPPER ANALYTICAL RESULTS FOR SITE 3 OFFSITE WELLS (PHASE II)*

	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Offsite Well No. 1						
level 1	--[†]	<0.01	<0.01	<0.01	<0.01	<0.01
level 2	<0.01	0.10	0.01	0.10	<0.01	<0.01
level 3	0.33	<0.01	<0.01	0.12	0.03	<0.01
level 4	0.16	--	--	--	--	--
Offsite Well No. 2						
level 1	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
level 2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
level 3	<0.01	<0.01	0.14	<0.01	<0.01	<0.01
level 4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Offsite Well No. 3						
level 1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
level 2	0.01	<0.01	0.06	0.06	<0.01	<0.01
level 3	<0.01	<0.01	<0.01	0.01	0.04	<0.01
level 4	--	<0.01	--	--	--	--
Offsite Well No. 4						
level 1	0.33	<0.01	0.12	0.05	<0.01	<0.01
level 2	0.21	0.03	<0.01	0.10	0.03	<0.01
level 3	0.08	0.05	0.03	0.20	0.15	<0.01
level 4	<0.01	<0.01	--	--	--	--
Offsite Well No. 5						
level 1	0.26	<0.01	0.04	0.04	0.12	<0.01
level 2	0.37	0.24	--	--	0.55	0.11
level 3	0.22	0.11	<0.01	0.39	0.15	0.26
level 4	0.16	0.06	0.22	<0.01	0.23	0.47
Offsite Well No. 6						
level 1	0.28	0.01	<0.01	0.12	0.01	<0.01
level 2	<0.01	<0.01	0.03	0.05	0.01	0.11
level 3	0.02	0.03	0.16	0.22	0.14	0.12
level 4	0.04	<0.01	<0.01	0.10	0.16	0.07

*Concentrations in ppm.

[†] -- Insufficient sample.

TABLE 3I. IRON ANALYTICAL RESULTS FOR SITE 3 OFFSITE WELLS (PHASE II)*

	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Offsite Well No. 1						
level 1	--†	0.3	4.6	8.2	8.9	6.9
level 2	2.9	120.0	16.0	176.0	7.6	6.9
level 3	140.0	27.0	6.4	152.0	32	7.1
level 4	44.0	--	--	--	--	--
Offsite Well No. 2						
level 1	5.3	8.2	31.0	31.0	31.0	49.0
level 2	1.4	0.5	13.0	29.0	28.0	32.0
level 3	0.03	3.7	180.0	88.0	15.0	3.7
level 4	0.1	5.5	9.2	35.0	4.7	1.9
Offsite Well No. 3						
level 1	84.0	3.5	57.0	409.0	49.0	91.0
level 2	5.9	38.0	61.0	284.0	17.0	41.0
level 3	0.5	270.0	220.0	291.0	231.0	32.0
level 4	--	160.0	--	--	--	--
Offsite Well No. 4						
level 1	120.0	3.3	69.0	125.0	4.5	2.2
level 2	120.0	66.0	5.3	109.0	36.0	3.9
level 3	140.0	160.0	23.0	203.0	96.0	5.6
level 4	1.5	<0.01	--	--	--	--
Offsite Well No. 5						
level 1	83.0	0.3	28.0	186.0	59.0	11.0
level 2	230.0	82.0	--	--	347.0	279.0
level 3	81.0	40.0	0.02	144.0	56.0	78.0
level 4	105.0	60.0	110.0	81.0	258.0	114.0
Offsite Well No. 6						
level 1	83.0	9.7	0.3	66.0	7.8	5.4
level 2	420.0	6.6	44.0	246.0	30.0	264.0
level 3	13.0	16.0	85.0	106.0	80.0	90.0
level 4	26.0	1.4	2.5	186.0	210.0	111.0

*Concentration in ppm.

†-- Insufficient sample.

TABLE 3J. MERCURY ANALYTICAL RESULTS FOR SITE 3 OFFSITE WELLS (PHASE II)*

	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Offsite Well No. 1						
level 1	--[†]	<0.0002	0.0020	<0.0002	0.0008	<0.0002
level 2	<0.0002	<0.0002	0.0020	0.0005	<0.0002	<0.0002
level 3	<0.0002	0.0020	0.0030	0.0003	<0.0002	<0.0002
level 4	0.0005	--	--	--	--	--
Offsite Well No. 2						
level 1	0.0003	0.0002	--	0.0004	0.0004	<0.0002
level 2	<0.0002	0.0010	0.0030	0.0006	<0.0002	<0.0002
level 3	0.0004	0.0009	0.0030	0.0002	<0.0002	<0.0002
level 4	<0.0002	0.0003	0.0030	0.0002	<0.0002	0.0040
Offsite Well No. 3						
level 1	0.0002	<0.0002	0.0020	<0.0002	<0.0002	0.0030
level 2	0.0027	0.0002	0.0030	<0.0002	<0.0002	0.0020
level 3	<0.0002	<0.0002	0.0030	<0.0002	<0.0002	<0.0002
level 4	--	<0.0002	--	--	--	--
Offsite Well No. 4						
level 1	<0.0002	<0.0002	0.0010	<0.0002	<0.0002	<0.0002
level 2	<0.0002	<0.0002	0.0010	<0.0002	<0.0002	<0.0002
level 3	<0.0002	<0.0002	0.0010	0.0003	<0.0002	<0.0002
level 4	<0.0002	<0.0002	--	--	--	--
Offsite Well No. 5						
level 1	0.0005	<0.0002	0.0010	<0.0002	<0.0002	<0.0002
level 2	--	<0.0002	--	--	0.0007	0.0018
level 3	<0.0002	<0.0002	<0.0002	0.0004	0.0005	<0.0002
level 4	0.0010	<0.0002	<0.0002	0.0003	0.0004	<0.0002
Offsite Well No. 6						
level 1	<0.0002	<0.0002	0.0005	0.0003	0.0007	<0.0002
level 2	<0.0002	0.0010	0.0010	0.0003	0.0004	<0.0002
level 3	<0.0002	<0.0002	0.0005	0.0003	0.0005	<0.0002
level 4	<0.0002	0.0007	0.0010	<0.0002	0.0005	0.0022

*Concentrations in ppm.

[†] -- Insufficient sample.

TABLE 3K . NICKEL ANALYTICAL RESULTS FOR SITE 3 OFFSITE WELLS (PHASE II)*

	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Offsite Well No. 1						
level 1	-- †	<0.01	<0.01	<0.01	<0.01	<0.01
level 2	<0.01	0.14	0.02	0.30	0.05	0.01
level 3	0.20	0.06	<0.01	0.04	0.02	0.01
level 4	0.15	--	--	--	--	--
Offsite Well No. 2						
level 1	<0.01	0.06	0.03	0.03	0.01	0.05
level 2	<0.01	0.01	<0.01	0.03	<0.01	<0.01
level 3	<0.01	0.01	0.28	<0.20	0.01	<0.01
level 4	<0.01	<0.01	<0.01	<0.20	<0.01	<0.01
Offsite Well No. 3						
level 1	0.13	<0.01	0.02	0.23	<0.01	0.05
level 2	0.01	0.06	0.10	0.09	<0.01	0.03
level 3	0.01	0.25	0.28	0.09	0.17	0.03
level 4	--	0.10	--	--	--	--
Offsite Well No. 4						
level 1	0.24	<0.01	0.14	0.08	<0.01	<0.01
level 2	0.16	0.04	<0.01	0.12	0.07	<0.01
level 3	0.24	0.21	0.08	0.24	0.20	<0.01
level 4	<0.01	<0.01	--	--	--	--
Offsite Well No. 5						
level 1	0.22	<0.01	0.06	0.29	0.16	0.02
level 2	0.49	0.23	--	--	0.17	0.56
level 3	0.23	0.12	0.04	0.34	0.16	0.33
level 4	0.23	0.11	0.37	0.21	0.65	0.43
Offsite Well No. 6						
level 1	0.24	0.03	<0.01	0.11	0.016	<0.01
level 2	0.47	0.02	0.06	0.08	0.03	0.37
level 3	0.03	0.03	0.19	0.08	0.19	0.15
level 4	0.05	<0.01	0.01	0.26	0.31	0.12

*Concentrations in ppm.

†-- Insufficient samples.

TABLE 3L. LEAD ANALYTICAL RESULTS FOR SITE 3 OFFSITE WELLS (PHASE II)*

	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Offsite Well No. 1						
level 1	--†	<0.005	<0.005	<0.005	<0.005	<0.005
level 2	<0.005	0.074	0.040	0.172	0.068	0.011
level 3	0.140	0.054	0.007	0.061	0.007	0.004
level 4	0.170	--	--	--	--	--
Offsite Well No. 2						
level 1	<0.005	0.054	--	0.023	<0.005	--
level 2	<0.005	0.008	<0.005	--	<0.005	<0.005
level 3	<0.005	<0.005	--	0.025	0.007	<0.005
level 4	<0.005	<0.005	--	0.010	<0.005	<0.005
Offsite Well No. 3						
level 1	0.040	<0.005	0.005	0.008	<0.005	0.045
level 2	0.010	0.043	0.060	0.071	<0.005	0.037
level 3	<0.005	0.005	0.020	0.082	0.200	0.035
level 4	--	0.005	--	--	--	--
Offsite Well No. 4						
level 1	0.210	0.009	0.200	0.102	<0.005	<0.005
level 2	0.190	0.080	0.008	0.135	0.082	<0.005
level 3	0.010	0.014	0.050	0.227	0.230	<0.005
level 4	<0.005	<0.005	--	--	--	--
Offsite Well No. 5						
level 1	0.200	<0.005	--	0.207	0.200	0.031
level 2	0.400	0.160	--	--	--	0.850
level 3	0.100	0.160	<0.005	--	0.200	0.450
level 4	0.210	0.190	0.400	<0.001	0.140	0.460
Offsite Well No. 6						
level 1	0.100	0.180	<0.005	0.104	0.006	<0.005
level 2	0.100	0.012	0.070	0.083	0.028	0.510
level 3	0.040	0.039	--	0.100	0.420	0.260
level 4	0.060	<0.005	<0.005	0.100	0.200	0.290

*Concentration in ppm.

†-- Insufficient sample.

TABLE 3M. ZINC ANALYTICAL RESULTS FOR
FOR SITE 3 OFFSITE WELLS (PHASE II)*

	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Offsite Well No. 1						
level 1	--[†]	0.07	0.03	0.73	0.07	0.03
level 2	<0.01	0.85	0.15	1.40	0.03	0.10
level 3	1.70	0.12	0.04	0.73	0.17	0.02
level 4	0.54	--	--	--	--	--
Offsite Well No. 2						
level 1	0.01	0.01	0.10	1.50	0.03	1.90
level 2	0.01	0.01	0.03	1.40	0.03	0.04
level 3	<0.01	0.03	0.92	0.62	0.08	0.01
level 4	<0.01	0.01	0.10	0.26	0.01	0.05
Offsite Well No. 3						
level 1	0.96	0.01	0.09	1.00	0.03	0.21
level 2	0.08	0.11	0.37	1.20	0.03	0.17
level 3	0.05	0.77	0.98	1.60	1.00	0.17
level 4	--	0.43	--	--	--	--
Offsite Well No. 4						
level 1	1.10	0.05	0.62	0.56	0.07	0.10
level 2	0.79	0.22	0.07	0.55	0.20	0.14
level 3	0.91	0.57	0.17	1.10	0.53	0.09
level 4	0.01	0.01	--	--	--	--
Offsite Well No. 5						
level 1	1.00	0.01	0.21	0.90	0.49	0.08
level 2	1.10	0.70	--	--	2.40	1.60
level 3	0.88	0.28	0.02	0.91	0.64	0.95
level 4	0.95	0.71	1.10	0.31	1.20	0.85
Offsite Well No. 6						
level 1	0.80	0.06	0.01	0.50	0.12	0.04
level 2	1.20	0.19	0.21	0.87	0.15	0.86
level 3	0.14	0.17	0.63	1.30	1.70	3.20
level 4	0.23	0.02	0.04	0.91	1.00	0.44

* Concentrations in ppm.

[†] -- Insufficient sample.

TABLE 3N. SPECIFIC CONDUCTANCE ANALYTICAL RESULTS FOR SITE 3 OFFSITE WELLS (PHASE II)*

	Sample Dates					
	11/1/76	1/20/77	3/8/77	5/16/77	7/18/77	9/12/77
Off-Site Well No. 1						
level 1	--†	1420	1040	--	950	880
level 2	--	1120	1000	--	950	920
level 3	--	1240	97	--	980	950
level 4	--	--	--	--	--	--
Off-Site Well No. 2						
level 1	--	10000	1700	--	1320	1310
level 2	--	1400	1500	--	2150	2150
level 3	--	83	84	--	930	830
level 4	--	90	80	--	900	890
Off-Site Well No. 3						
level 1	--	2000	2000	--	1800	1320
level 2	--	1260	1340	--	1450	1230
level 3	--	1200	1060	--	1200	1040
level 4	--	1540	--	--	--	--
Off-Site Well No. 4						
level 1	--	62	54	--	600	500
level 2	--	68	55	--	600	385
level 3	--	1000	81	--	600	610
level 4	--	83	--	--	--	--
Off-Site Well No. 5						
level 1	--	85	75	--	780	470
level 2	--	78	--	--	--	670
level 3	--	470	73	--	670	540
level 4		64	60	--	600	360
Off-Site Well No. 6						
level 1	--	1120	95	--	1120	1040
level 2	--	82	95	--	1080	1020
level 3	--	1100	1020	--	1100	1030
level 4		1200	88	--	980	900

*Specific conductance in μmhos/cm.

†--Insufficient sample.

TABLE 4. ANALYTICAL RESULTS FOR SITE 4, PHASE II

Sample Date	Constituents*											
	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	Cl	SO_4	TOC	Sp. Cond.
Background Well												
11/23/76	<0.001	<0.01	<0.01	3.20	<0.0002	<0.01	0.005	0.04	83	90	117	--†
1/19/77	0.001	<0.01	<0.01	0.26	0.0007	<0.01	0.046	0.11	13	7	24	66
3/7/77	0.001	<0.01	<0.01	<0.01	0.0003	<0.01	0.006	0.08	8	60	13	42
5/21/77	<0.001	<0.01	<0.01	0.04	<0.0002	<0.01	0.070	0.20	6	40	2	--
7/21/77	<0.001	<0.01	<0.01	0.07	0.0030	<0.01	0.028	0.06	7	65	1	525
9/16/77	<0.001	<0.01	<0.01	0.90	0.0190	0.12	0.220	0.26	180	46	6	1010
In-Refuse Well												
11/23/76	0.010	0.06	0.07	13.00	<0.0002	0.12	0.200	0.13	4	1	146	--
1/19/77	<0.005	0.85	0.08	1.50	0.0005	0.09	0.090	0.23	4	5	485	2650
3/7/77	0.005	0.11	0.05	0.80	0.0002	0.09	0.470	0.29	5	10	128	520
5/21/77	0.005	0.14	0.05	0.21	<0.0002	0.18	0.080	0.12	2	1	105	--
7/21/77	<0.005	0.14	0.08	20.00	0.0002	0.12	0.095	0.04	4	<1	97	6900
9/16/77	<0.005	0.11	0.03	13.00	<0.0002	0.07	0.150	0.08	2	<1	93	6025
Shallow Off-Site Well (OS-1)												
11/23/76	0.001	0.01	<0.01	1.60	<0.0002	<0.01	0.130	0.06	10	1160	<1	--
1/19/77	0.002	0.01	0.01	3.30	0.0020	<0.01	1.800	2.20	83	1120	7	6500
3/7/77	0.003	<0.01	0.01	0.27	<0.0002	0.07	0.260	0.77	120	1285	17	240
5/21/77	0.002	0.01	0.01	0.07	0.0010	<0.01	0.125	0.49	<2	1325	7	--
7/21/77	0.001	<0.01	<0.01	0.06	0.0004	<0.01	0.086	0.37	<2	1330	5	3100
9/16/77	0.003	0.01	<0.01	0.45	0.0007	0.02	0.087	0.14	<2	1650	3	3010

*Specific conductance in µmhos/cm, all other constituents concentrations in ppm.

†-- Insufficient sample.

TABLE 5. ANALYTICAL RESULTS FOR SITE 5, PHASE II

Sample Date	Constituents*											
	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	Cl	SO_4	TOC	Sp. Cond.
Background Well												
11/15/76	0.002	<0.01	0.01	4.40	<0.0002	0.01	0.260	0.09	37	9	30	130
1/21/77	<0.001	<0.01	<0.01	0.82	0.0010	<0.01	0.010	<0.01	10	145	24	--†
4/1/77	<0.001	<0.01	<0.01	2.60	0.0005	<0.01	0.010	0.04	9	1	11	--
5/19/77	0.001	<0.01	0.01	0.97	<0.0002	<0.01	<0.005	0.01	11	1	8	86
8/1/77	<0.001	<0.01	<0.01	0.37	0.0002	<0.01	<0.005	0.02	13	2	4	--
9/21/77	<0.001	<0.01	0.01	0.53	0.0041	<0.01	0.005	0.41	21	1	1	120
Off-Site Well (OS-1)												
11/15/76	0.005	0.01	0.19	65.00	<0.0002	0.04	0.040	0.07	61	14	23	500
1/21/77	0.009	0.03	0.55	230.00	0.0010	0.08	0.100	0.13	32	130	21	--
4/1/77	0.010	0.03	0.41	130.00	0.0003	0.06	0.040	0.18	33	23	9	--
5/19/77	0.004	0.02	0.27	80.00	<0.0002	0.03	0.031	0.14	27	32	5	560
8/1/77	0.008	0.06	0.37	110.00	0.0004	0.06	0.074	0.21	41	50	7	--
9/21/77	0.001	<0.01	0.04	28.00	0.0005	0.01	0.005	0.11	33	35	5	660

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* Specific conductance in μmhos/cm, all other constituents concentrations in ppm.

† -- Insufficient sample.

TABLE 6. ANALYTICAL RESULTS FOR SITE 6, PHASE II

Sample Date	Constituents*											
	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	Cl	SO_4	TOC	Sp. Cond.
Background Well												
11/10/76	<0.001	<0.01	<0.01	3.80	<0.0002	0.03	0.030	0.12	28	13	15	70[†]
1/10/77	<0.001	<0.01	<0.01	1.00	<0.0002	<0.01	0.005	0.12	7	3	4	--
3/30/77	<0.001	<0.01	<0.01	1.10	0.0005	<0.01	<0.005	0.06	6	3	3	33
5/17/77	<0.001	<0.01	<0.01	0.56	<0.0002	<0.01	<0.005	0.01	5	2	1	36
7/26/77	< 0.001	<0.01	<0.01	0.99	< 0.0002	<0.01	<0.005	0.07	9	4	3	--
9/16/77	0.001	<0.01	<0.01	0.77	<0.0002	<0.01	<0.005	0.13	9	2	3	34
Off-Site Well No. 3 Level 1 (OS-31)												
11/10/76	<0.001	<0.01	<0.01	2.50	0.0003	0.02	0.020	0.03	20	30	8	165
1/10/77	--	--	--	--	--	--	--	--	--	--	--	--
3/30/77	--	--	--	--	--	--	--	--	--	--	--	--
5/17/77	<0.001	<0.01	<0.01	3.10	0.0002	<0.01	0.025	0.01	5	6	--	--
7/26/77	0.004	< 0.01	< 0.01	0.02	0.0005	< 0.01	0.019	< 0.01	--	--	--	--
9/16/77	--	--	--	--	--	--	--	--	--	--	--	--
Off-Site Well No. 3 Level 2 (OS-32)												
11/10/76	<0.001	<0.01	<0.01	3.30	<0.0002	<0.01	0.030	0.02	146	11	2	165
1/10/77	<0.001	<0.01	<0.01	3.90	<0.0002	<0.01	0.044	0.09	6	6	1	--
3/30/77	<0.001	<0.01	<0.01	4.00	<0.0002	<0.01	0.040	0.04	6	7	5	--
5/17/77	<0.001	<0.01	0.03	0.46	<0.0002	<0.01	<0.005	0.02	2	3	1	44
7/26/77	0.001	0.01	0.08	3.90	0.0004	0.01	< 0.025	0.29	9	8	15	--
9/16/77	0.001	<0.01	<0.01	0.97	<0.0002	0.01	<0.005	0.02	9	5	3	48
Off-Site Well No. 3 Level 3 (OS-33)												
11/10/76	<0.001	<0.01	<0.01	9.30	<0.0002	0.01	0.040	0.06	51	11	3	75
1/10/77	<0.001	<0.01	<0.01	3.10	<0.0002	<0.01	0.015	0.04	6	2	4	--
3/30/77	<0.001	<0.01	<0.01	3.40	0.0003	<0.01	<0.005	0.03	4	3	4	--
5/17/77	<0.001	<0.01	<0.01	3.60	0.0025	0.03	0.009	0.01	5	3	3	30
7/26/77	<0.001	<0.01	<0.01	4.50	<0.0002	<0.01	<0.005	0.03	8	4	1	--
9/16/77	<0.001	<0.01	<0.01	0.27	<0.0002	<0.01	<0.005	<0.01	8	1	4	40

TABLE 6. (continued)

Sample Date	Constituents											
	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	Cl	SO_4	TOC	Sp. Cond.
Off-Site Well No. 1 (OS-1)												
11/10/76	<0.001	<0.01	<0.01	1.50	0.0003	0.02	0.030	0.01	27	4	3	55
1/10/77	<0.001	<0.01	<0.01	0.12	<0.0002	<0.01	0.026	0.12	5	2	1	--
3/30/77	--	--	--	--	--	--	--	--	--	--	--	--
5/17/77	--	--	--	--	--	--	--	--	--	--	--	--
7/26/77	0.004	0.01	0.01	0.03	0.0005	0.01	0.020	0.02	--	--	--	--
9/16/77	--	--	--	--	--	--	--	--	--	--	--	--
Off-Site Well No. 2 (OS-2)												
11/10/76	--	--	--	--	--	--	--	--	--	--	--	--
1/10/77	--	--	--	--	--	--	--	--	--	--	--	--
3/30/77	<0.001	<0.01	<0.01	0.09	0.0002	<0.01	<0.005	0.07	3	3	1	41
5/17/77	--	--	--	--	--	--	--	--	--	--	--	--
7/26/77	<0.001	<0.01	<0.01	0.11	0.0004	<0.01	<0.005	0.02	6	4	1	44
9/16/77	0.002	<0.01	<0.01	0.21	<0.0002	<0.01	<0.005	0.08	4	3	2	--

*Specific conductance in µmhos/cm, all other constituents concentrations in ppm.

†-- Insufficient sample.

TABLE 7. ANALYTICAL RESULTS FOR SITE 7, PHASE II

Sample Date	Constituents*											
	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	Cl	SO_4	TOC	Sp. Cond.
Background Well												
11/12/76	<0.001	0.01	<0.01	6.20	<0.0002	0.02	0.020	0.05	14	9	225	57
1/11/77	<0.001	<0.01	<0.01	1.10	0.0006	<0.01	<0.005	0.04	8	10	8	--†
3/31/77	<0.001	<0.01	0.03	5.30	<0.0002	0.01	0.007	0.05	3	8	2	--
5/18/77	<0.001	<0.01	0.01	0.69	<0.0002	<0.01	<0.005	0.02	4	8	4	250
7/26/77	<0.001	<0.01	<0.01	3.30	<0.0002	<0.01	<0.005	0.01	5	10	2	--
9/19/77	<0.001	<0.01	0.01	4.70	<0.0002	0.01	0.008	0.03	4	8	1	240
In-Refuse Well												
11/12/76	<0.001	0.03	<0.01	1.60	<0.0002	0.01	0.005	0.19	36	1	184	4115
1/11/77	0.010	0.12	0.03	9.40	<0.0002	0.06	0.060	0.26	5	1	78	--
3/31/77	<0.005	0.08	0.03	4.70	0.0002	0.05	0.050	0.14	3	6	395	--
5/18/77	0.010	<0.01	0.04	6.00	0.0011	0.11	0.020	0.06	3	10	69	4400
7/26/77	<0.005	<0.08	0.01	2.70	0.0002	0.12	0.250	0.08	26	15	59	--
9/19/77	0.005	0.15	0.05	7.80	0.0008	0.15	0.040	0.15	423	1	94	10000
Garage Water Well												
11/12/76	<0.001	<0.01	<0.01	0.25	<0.0002	<0.01	0.005	2.30	28	10	4	--

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*Specific conductance in μmhos/cm, all other constituents concentrations in ppm.

†-- Insufficient sample.

TABLE 7. (continued)

Sample Date	Constituents*											
	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	Cl	SO_4	TOC	Sp. Cond
Off-Site Well No. 1 (OS-1)												
11/12/76	0.001	0.01	0.01	12.0	0.0003	0.03	0.050	0.08	171	9	44	635
1/11/77	<0.001	<0.01	0.03	14.0	0.0007	0.03	0.064	0.29	42	10	16	--[†]
3/31/77	<0.001	<0.01	0.04	9.6	0.0040	0.02	0.040	0.18	78	9	8	--
5/18/77	0.001	<0.01	<0.01	5.0	<0.0002	0.01	<0.005	0.01	209	7	26	1200
7/26/77	0.001	<0.01	<0.01	14.0	<0.0011	0.04	<0.047	0.05	26	1	16	--
9/19/77	0.002	0.01	0.10	26.0	0.0008	0.05	0.033	0.13	13	2	10	1500
Off-Site Well No. 2 (OS-2)												
11/12/76	0.001	<0.01	<0.01	1.7	<0.0002	0.02	0.010	0.23	108	6	19	555
1/11/77	<0.001	<0.01	<0.01	3.4	0.0003	0.02	<0.005	0.12	52	8	17	--
3/31/77	<0.001	<0.01	0.02	3.0	0.0004	0.01	0.008	0.10	58	4	9	--
5/18/77	<0.001	<0.01	0.01	1.6	<0.0002	<0.01	<0.005	0.02	79	1	17	680
7/26/77	<0.002	<0.01	<0.01	3.6	<0.0002	<0.02	<0.005	0.02	193	1	7	--
9/19/77	0.001	0.01	0.16	16.0	0.0007	0.02	0.021	0.14	26	1	8	2400
Off-Site Well No. 3 (OS-3)												
11/12/76	<0.001	<0.01	<0.01	6.3	0.0004	<0.01	0.005	0.02	124	6	39	740
1/11/77	<0.001	<0.01	<0.01	6.8	0.0007	0.01	0.009	0.14	66	10	5	--
3/31/77	<0.001	<0.01	<0.01	1.2	0.0004	<0.01	<0.005	0.03	52	8	3	--
5/18/77	<0.001	<0.01	<0.01	2.1	<0.0002	<0.01	<0.005	0.01	60	9	5	730
7/26/77	<0.001	<0.01	<0.01	3.9	0.0014	0.02	<0.005	0.01	117	10	6	--
9/19/77	0.001	0.01	<0.01	3.1	0.0003	0.03	<0.005	0.09	140	8	3	1000

*Specific conductance in μmhos/cm, all other constituents concentrations in ppm.

[†] -- Insufficient sample.

TABLE 8. ANALYTICAL RESULTS FOR SITE 8, PHASE II

Sample Date	Constituents*											
	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	Cl	SO_4	TOC	Sp. Cond.
Background Well												
11/11/76	<0.001	<0.01	<0.01	1.50	0.0009	<0.01	<0.005	0.01	17	40	7	280
1/12/77	0.002	<0.01	<0.01	0.43	0.0003	0.10	0.011	0.15	9	90	9	--†
3/30/77	<0.001	<0.01	<0.02	0.27	0.0004	<0.01	<0.005	0.03	7	100	5	--
5/18/77	<0.001	<0.01	0.01	0.17	<0.0002	<0.01	<0.005	0.02	6	115	5	720
7/26/77	<0.001	<0.01	<0.01	0.48	<0.0002	<0.01	<0.005	0.20	10	75	10	--
9/19/77	<0.001	<0.01	0.04	0.62	<0.0002	<0.01	<0.005	0.05	29	55	15	480
In-Refuse Well												
11/11/76	0.050	0.07	4.50	390.00		1.10	2.000	17.00	11	12	17	475
1/12/77	No Sample											
3/30/77	<0.005	0.25	0.11	21.00	0.0006	0.03	0.070	0.59	<2	3	21	--
5/18/77	0.005	0.17	0.83	85.00	0.0005	0.31	0.320	4.60	--	--	1	10,000
9/18/77	0.005	0.13	0.45	39.00	0.0010	0.10	0.210	2.40	11	14	71	340
Original Deep Off-Site Well (OS-2)												
11/11/76	<0.001	<0.01	<0.01	1.20	<0.0002	0.02	0.010	0.01	76	1	21	250
1/12/77	<0.001	<0.01	<0.01	88.00	0.0003	0.17	0.064	0.32	21	9	25	--
3/30/77	<0.001	<0.01	0.01	24.00	<0.0002	0.02	<0.005	0.18	16	9	14	--
5/18/77	0.002	<0.01	0.05	68.00	<0.0002	0.07	0.038	0.22	15	10	21	800
7/27/77	0.008	<0.09	0.23	204.00	<0.0002	0.22	0.056	0.56	21	10	18	--
9/18/77		<0.01	0.01	19.00	0.0005	<0.01		0.06	14	70	11	500

*Specific conductance in μmhos/cm, all other constituents concentrations in ppm.

†-- Insufficient sample.

TABLE 8. (continued)

Sample Date	Constituents *											
	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	Cl	SO_4	TOC	Sp. Cond.
Shallow Off-Site Well (OS-1)												
11/11/76	0.003	0.01	0.01	94.00	<0.0002	0.07	0.090	0.06	32	5	27	1060
1/12/77	<0.001	<0.01	<0.01	1.20	0.0006	<0.01	<0.005	0.39	11	3	18	--†
3/30/77	<0.001	<0.01	0.01	1.80	0.0013	0.02	<0.005	0.17	11	<1	9	--
5/18/77	<0.001	<0.01	0.04	0.82	0.0002	0.03	<0.005	0.14	8	<1	14	1400
7/27/77	<0.001	<0.01	0.04	18.00	<0.0002	0.03	<0.005	0.19	17	3	13	--
9/18/77	<0.001	<0.01	<0.01	0.52	0.0018	0.01	<0.005	0.07	17	1	9	340
Deep Off-Site Well (OS-3)												
11/11/76	0.001	<0.01	<0.01	1.10	<0.0002	0.16	<0.005	0.04	41	260	688	1165
1/12/77	<0.001	<0.01	<0.01	24.00	<0.0002	0.04	0.009	0.13	12	50	225	--
3/30/77	<0.001	<0.01	<0.01	0.35	<0.0002	<0.01	<0.005	<0.05	<2	37	268	--
5/18/77	<0.001	<0.01	0.03	30.00	<0.0002	<0.01	<0.005	0.07	<2	24	191	1000
7/27/77	<0.001	<0.01	<0.01	23.00	<0.0002	<0.01	<0.005	0.04	4	13	184	--
9/18/77	<0.001	<0.01	<0.01	65.00	0.0019	0.02	<0.005	0.03	<2	1	31	1000

*Specific conductance in μmhos/cm, all other constituents conentrations in ppm.

†-- Insufficient sample.

APPENDIX F

NATIONAL PRIMARY DRINKING WATER STANDARDS

Maximum Contaminant Levels for Inorganic Chemicals*

Contaminant	Level (mg/l)	Contaminant	Level (mg/l)
Arsenic	0.05	Lead	0.05
Barium	1.	Mercury	0.002
Cadmium	0.010	Nitrate-N	10
Chromium	0.05	Selenium	0.01
		Silver	0.05

Fluorides - When the annual average of the maximum daily air temperatures for the location in which the public water system is situated is the following, the corresponding concentration of fluoride shall not be exceeded:

Temperature (in degrees F)	(degrees C)	Level (mg/l)
50.0-53.7	10.0-12.0	2.4
53.8-58.3	12.1-14.6	2.2
58.4-63.8	14.7-17.6	2.0
63.9-70.6	17.7-21.4	1.8
70.7-79.2	21.5-26.2	1.6
79.3-90.5	26.3-32.5	1.4

Maximum Contaminant Levels for Organic Chemicals

The maximum contaminant level for the total concentration of organic chemicals is 0.7 mg/l.

Maximum Contaminant Levels for Pesticides

Chlorinated Hydrocarbons	Level (mg/l)
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005

Chlorophenoxys	Level (mg/l)
2,4-D	0.1
2,4,5-TP Silvex	0.01

Maximum Microbiological Contaminant Levels

Two methods may be used:

(1) When membrane filter technique is used, coliform densities shall not exceed one per 100 milliliters as arithmetic mean of all samples examined per month and either

- Four per 100 milliliters in more than one standard sample when less than 20 are examined per month; or
- Four per 100 milliliters in more than five percent of the standard samples when 20 or more are examined per month.

(2)(a) When fermentation tube method is used and 10 milliliter standard portions, coliforms shall not be present in more than 10 percent of the portions in any month; and either

- Three or more portions in one sample when less than 20 samples are examined per month; or
- Three or more portions in more than five percent of the samples if 20 or more samples are examined per month.

(b) When fermentation tube method is used and 100 milliliter standard portions, coliforms shall not be present in more than 60 percent of the portions in any month; and either

- Five or more portions in more than one sample when less than five samples are examined; or
- Five or more portions in more than 20 percent of samples when five samples or more are examined.

Maximum Contaminant Level of Turbidity

The level at representative entry point(s) to the distribution system is one turbidity unit (TU) except that five or fewer turbidity units may be allowed if supplier can demonstrate to State that higher turbidity does not:

- Interfere with disinfection;
- Prevent maintenance of an effective disinfectant agent through the distribution system; and
- Interfere with microbiological determinations.

*Secondary drinking water standards for chloride and sulfate are 250 mg/l, and for copper and zinc are 1 and 5 mg/l, respectively. The 1962 USPHS drinking water standard for iron is 0.3 mg/l.

μσ1715
SW-167c